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EMPIRICAL DETERMINATION OF WRSK COMPONENT FAILURE DISTRIBUTIONS

PREPARED BY

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Current methodology for determining components of a War Readiness Spares Kit (WRSK) is based on mean times to failure for the entire U.S. Air Force inventory. Failures on a specific aircraft type during a calendar period are divided by flying hours logged on that aircraft type during the same period. Kit configuration is then optimized using the Poisson distribution to approximate kit demand behavior. The Poisson process requires a single

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20. ABSTRACT

statistic, mean value of distribution, for which world-wide mean time to failures is used.

There are several alternatives to the Poisson distribution. Negative binomial distribution has been suggested as a more appropriate model, and it has been demonstrated that the WRSK configuration would change under this assumption.

To test the suitability of both distributions, two analyses were undertaken of mean time to verified failures of the fleet and assumed constant failure rate of WRSK items among the fleet. In both analyses, the hypothesis that data is Poisson distributed could not be rejected for the majority of the cases. In several cases, however, the Poisson distribution was rejected as an adequate fit for the data and the negative binomial was a viable alternative. Negative binomial also appeared to be a better model in some of the cases where the Poisson distribution could not be rejected.

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ABSTRACT

The current methodology by which the components of a War Readiness Spares Kit (WRSK) are determined are based on mean times to failure for the entire U.S. Air Force inventory. The failures on a specific aircraft type during a calendar period are divided by the flying hours logged on that aircraft type during the same period. The configuration of the kit is then optimized using the Poisson distribution to approximate the demand behavior on the kit. The Poisson process requires a single statistic, the mean value of distribution, for which the world-wide mean time to failures is used.

There are several alternatives to the use of a Poisson distribution. In particular, the negative binomial distribution has been suggested as a more appropriate model and it has been demonstrated that the configuration of the WRSK would change under this assumption.

Underlying the two distributions is a theoretical difference. The Poisson process arises when a fleet of aircraft have a constant failure rate associated with each component airplane, but the failure rates among the airplanes are distributed as a Poisson distribution. The negative binomial arises when the constant failure rates of the individual airplanes are distributed as a gamma distribution.

In order to test the suitability of the distributions, it is necessary to investigate the true distribution of failures among airplanes. The data are too aggregated to achieve this end after they have been collected from the bases, so data gathering was done at the base level. Maintenance records and flying hour records were each gathered from their points of origin.

Two such attempts to gather data were undertaken, one at Moody Air Force Base and the other at Cannon Air Force Base. The flying hour data at Moody were incomplete, and it was not possible to construct a sufficiently large

number of failure intervals for analysis. The data from Cannon were complete and the analysis proceeds from this data base.

Seven thousand and fifty-eight flying records, covering seventy-six airplanes from July 1979 to September 1980, were obtained from Cannon. Merging these records with the maintenance data produced 1146 intervals between verified failures of forty-one removable components on seventy-five airplanes. The 46 planes which flew at least 200 hours showed 1026 failures on 58 WUCs in their first 200 hours, while the 14 planes which flew at least 300 hours showed 323 failures on 43 WUCs in their first 300 hours.

Two types of analysis were undertaken. The first was an analysis of the mean time to verified failures for the fleet. In the majority of the cases, the hypothesis that the data is Poisson distributed could not be rejected, however, in some cases the Poisson distribution was rejected as an adequate fit of the data. The negative binomial is a viable alternative fit for the data. Even in some cases where the Poisson could not be rejected, the negative binomial appears to be a better model.

The second analysis tests the hypothesis that the assumed constant failure rate of WRSK items is Poisson distributed among the fleet aircraft. Again, the hypothesis could not be rejected for the majority of WRSK items, but could be rejected for several, indicating that the Poisson model is not an adequate fit for the fleet rate-of-failure distribution.

A test of effect of surge was run. Although there were several surge exercises during the period for which data were collected, there was only one major exercise, Coronet Hammer. Eighteen airplanes took part in this exercise. Those items which were affected by Coronet Hammer could be isolated and were dropped from the data set. The two tests were repeated. The interval test on the total fleet failure distribution for the reduced set showed no deviation from the adequacy of Poisson distribution. The

rate-of-failure distribution among airplanes in the fleet failed to show more homogeneity without consideration of surge-stressed items. The lack of confirmation that surge affects the rate of failure, makes the conclusions suspect. Since the aircraft that took part in Coronet Hammer flew more hours, they are over-represented in the sample. If they also display lower failure rates and were therefore selected, the results would be consistant.

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I. INTRODUCTION

A. BACKGROUND COMMENTS

The mission of the United States Air Force requires it to be ready to provide operational airplanes anywhere in the world on short notice. The deployment of these airplanes will not always include immediate access to normal supply channels for spare parts, yet maintenance will certainly be required.

The War Readiness Spares Kit (WRSK) is an air transportable package of spare parts designed to maintain a specified number of airplanes as a fleet capable of performing its mission for a specified period of time, in case the airplanes are deployed beyond the reach of normal supply channels.

For example, a typical F111D WRSK is designed to support twenty-four planes for a thirty day, 1723 flying hour program. It contains 994 component items with from 1 to 144 units of each item, ranging in cost from $0.01 per unit to $566,500.00 per unit, for a total of 3366 units and a total cost of $144,849,767.00.

In order to make the best use of the taxpayers' dollars, it is important that no more parts be included in the WRSK than will be necessary to maintain the fleet for the desired flying hour period and mission. For the F111D kit, a ten percent excess in stockage may cost over fourteen million dollars. Yet, it is also important that the kit actually be capable of supporting the fleet as it is intended.

B. CALCULATION OF THE INITIAL WRSK

The determination of which items will be included in the WRSK is both a mechanical and a political process. It is influenced to some extent by the apparent likelihood of failure of an item, to some extent by safety considerations, and to some extent by interaction among the system manager and his

using organizations. The process of selection has been thoroughly described elsewhere (Rasmussen and Stover, 1978: 10-14). In summary, the following factors are considered by the system manager in preparing a list of candidates for inclusion (Morrison and Probst, 1975, cited in Rasmussen and Stover, 1978: 10-11):

1. Probability of demand
2. Mission essentiality
3. Dimension (certain size limitations are set due to palletization requirements)
4. Maintenance capability
5. Remove and replace time

If it were possible to say precisely how many of each item would break down during deployment, the kit could be made up of just those exact parts, in the precise quantities that would be needed. In fact, there is uncertainty. It is necessary to estimate how many units of each item will be needed. This estimate is based on information about past performance of the part. For example, if it is known that in the past, four transducers failed in twelve hundred flying hours, then, assuming a constant failure rate, ten transducers would fail in three thousand flying hours. This information can be calculated for each individual part, or item.

Once the list of items has been developed, the quantity of each item to be included in the WRSK must be calculated. In general, a demand rate expressed in units per flying hour is multiplied by the total flying hour program that the kit is designed to support. The calculations include modifications to allow for repair capability, if any, at the deployment site.

If the item is not repairable, the initial list quantity is obtained as follows (Rasmussen and Stover, 1978: 14):

Initial list quantity = D X QPA X R , where

D = Organizational and field maintenance demand rate, in units per unit flying hour,

QPA = Quantity of the item per aircraft, and

R = Wartime flying hour program.

If the item is repairable, the initial list quantity is obtained as follows (Rasmussen and Stover, 1978: 14):

Initial list quantity = DD X QPA X R + BR X QPA X RC , where

DD = Organizational and field maintenance demand rate, in units per unit flying hour,

BR = Base repair rate of the item, and

RC = Base repair cycle program--the number of days required to repair the item, usually impressed as three days.

Additional modifications may be used to allow for setup time of repair facilities at the forward site, and for a flying hour program that varies daily.

The list is then negotiated with the using major command, taking into account whether or not the item is a safety-of-flight or a time change item. The F111D kit described above was designed by this method.

C. OPTIMIZATION OF THE WRSK

After the kit is initially calculated, it is optimized. Optimization refers to improving the efficiency with which money is spent on the WRSK. The resulting kit costs no more than the initial kit, and is at least as adequate as the original kit was. For the WRSK, adequacy is measured in terms of the expected number of Stock Due Outs (SDO's), or outstanding backorders, and the expected number of Not Mission Capable (NMC) airplanes. There are several methods of optimization available (Messinger and Shooman, 1970). In the case

of the WRSK, optimization is accomplished by a process known as marginal analysis.

As Chen pointed out (1979: 9), marginal analysis may begin with an empty initial kit, or with a large initial kit, or with the existing kit composition, but "different initial kits will result in different final kit compositions, which, in turn, vary greatly in terms of cost and level of readiness." Chen endorsed using the conventional kit as a starting point (1979: 15). Chen also developed an algorithm to use another optimization method, the branch and bound technique, to optimize the WRSK (1979: 17-29).

The WRSK is currently calculated using marginal analysis, with the conventional kit as the initial kit.

As an example, the F111D WRSK described above was optimized by the use of the marginal analysis technique. The total cost of the kit dropped from $144,849,767.00 to $129,527,231.00. a savings of 10.5%. The expected number of NMC aircraft dropped from 11.32 to 11.29, and the expected SDO dropped from 563.016 to 476.610. The total number of units rose from 3366 with the conventional kit to 4277 with the marginal analysis kit. So, in this case, the performance of the kit was improved under both criteria, while the cost was reduced by over ten percent.

This improvement is obtained by comparing the advantage to be gained by including any one item with the advantage to be gained by adding any other. The item which gives the greater advantage per dollar provides the more efficient use of the money allocated for the WRSK.

In comparing advantage, it is necessary to compare the relative likelihood of events. This can be done by the use of probability distributions. Probability distributions allow calculations that will give the likelihood of one failure, or two failures, or of any number of failures, if enough is known about the past behavior of the part. For the Poisson distribution, all that

it is necessary to know is the average failure rate, and since this information is convenient to obtain and simple to calculate, as demonstrated above, the Poisson distribution is used in the WRSK calculations.

Using the Poisson probability distribution, also called the Poisson probability density function, it is possible to calculate the expected number of SDO and of NMC aircraft. Then, that spare can be added to the stock that reduces the expected number of SDO and NMC at the lowest possible additional cost.

For example, suppose both a discriminator, costing $511.90, and a valve, costing $9,322.00, have the same expected number of failures, and the same expected number of Not Mission Capable aircraft if they are not added to the WRSK. The advantage of removing an aircraft from NMC status costs $511.90 if the discriminator is included, and $9,322.00 if the valve is included. So the discriminator provides the same advantage, more cheaply.

The actual calculations for the WRSK allow for cases with more than one unit of the same item on the airplane, and with different failure rates. With the large number of items included in the WRSK, the marginal analysis calculations are computerized.

The initial or "conventional" kit, the marginal analysis kit, and the other optimization procedure developed by Chen all depend on the use of an average total demand rate calculated on data gathered on all bases worldwide. Because this average demand rate is used, a Poisson probability distribution is used to calculate the likelihood of failure, and expected SDOs and NMC aircraft.

D. DISCRETE AND CONTINUOUS DISTRIBUTIONS

The Poisson distribution is a member of a class of distributions that are called discrete distributions, because they give the likelihood of whole items--how many events occur in a period of time, how many holes are dug in an

acre, and so on. This is called a discrete distribution because the items being counted are discrete, or separate, and indivisible. For a discrete distribution, it is possible to say, "there is a ten percent chance of failure in the first ten minutes," but it is not possible to say, "there is a twenty percent chance of half a failure in fifteen minutes." The event in question is indivisible.

On the other hand, suppose the question is, how much time occurs between failures? There might be an hour between failures, or half an hour, or twenty-three and a third seconds. Time is not discrete, or indivisible, and the type of probability distribution that is used to discuss the distribution of time is called a continuous distribution, because it gives the likelihood of a continuous item.

Either a continuous or a discrete distribution may be used to describe a given situation, discrete if the events or occurrences are being counted, continuous if the intervals between events or occurrences are being examined.

There is an intimate relationship between certain discrete and certain continuous distributions. In any case where a Poisson discrete distribution describes the distribution of events, the exponential continuous distribution describes the distribution of the intervals between events. This result is extremely useful because, if it is difficult or impractical to examine one set of statistics, it may still be possible to examine the other set, and if one type of distribution can be established, it establishes the other. Proving the presence of a Poisson discrete distribution proves the exponential continuous distribution. This result is so important that the entire system is referred to as a Poisson process. When a Poisson process is referred to, it automatically implies an exponential continuous distribution of the interarrival times.

Another discrete distribution is the negative binomial distribution. Like the Poisson, it is used when the distribution of the discrete events is needed. When a lot of individual airplanes have different constant occurrence rates for some event, and the different constants are distributed by the gamma distribution, then the negative binomial describes the total distribution over all individuals.

It has recently been shown (Bain and Wright, 1981) that a certain continuous distribution, related to Snedecor's F, is to be expected when the negative binomial distribution describes the distribution of the events. If the Bain-Wright interarrival times are present, then the negative binomial describes the distribution of events. If it can be shown that a negative binomial distribution describes the distribution of events, then a Bain-Wright interarrival distribution has also been demonstrated. If one is known, the other is known.

Among other continuous distributions, Hahn and Shapiro (1967: 118) note, "the gamma and log-normal distributions have been advanced as time-to-failure distributions on both theoretical and empirical grounds."

Other discrete distributions which might describe the distribution of failures include the Pascal and the geometric distributions. The negative binomial distribution is a generalization of the Pascal distribution, and the two are often discussed together, while the geometric distribution is a special case of the Pascal distribution.

E. POSSIBLE INADEQUACY OF THE POISSON

As mentioned above, the Poisson distribution is currently used to calculate the WRSK. The use of the Poisson carries with it certain implications: that the failures are independent, and that the failure rate is a constant. If the failure rate of a part were not constant, or if the failure of a part depended on the previous history of the equipment, another probability

distribution might be more appropriate for that part. This does not mean that the Poisson would not be adequate to describe worldwide behavior and need for that spare part. In any case where data from a large number of sources are being combined, a certain smoothing effect occurs. Thus, demand for a part over the entire Air Force may indeed follow a Poisson distribution, but that may be because the aggregation of a large number of sources has eliminated the effects at the unit level of such variables as weather, experience of the mechanics, personnel transfers, command emphasis, and so on. Large peaks of demand at the local level are smoothed out by the time they reach the depot supply point.

At the local level, or even at the level of the individual airplane, there may be another probability model that would better describe the distribution of failures of some items included in the WRSK. Would that have any significant effect on the ability of the WRSK to support a fleet?

In a very focused attempt to examine the failure distributions of aircraft equipment, Johnson and McCoy (1978) studied the behavior of three inertial measurement units. They based their analysis on the arrival dates of unserviceable units at the maintenance depot, without regard for possible marshaling of shipments. Thus (Johnson and McCoy, 1978: 15), "multiple arrivals on a given date were indicated by multiple occurrences of that date on the file." The file of "failure" dates was then sorted chronologically, and partitioned into overlapping data sets. The first eight quarters of data were grouped into the first subset, then the initial quarter was dropped and the ninth added, to form the second population subset, and so on. Each of these "base periods" for each IMU was analysed separately.

The Kolmogorov-Smirnov test was used to determine if any of the population subsets fit the Poisson distribution. None of the base periods of any of the three IMU's could be fit to the Poisson distribution.

The next test performed was a calculation of the variance-to-mean ratio. The variance-to-mean ratio of the Poisson distribution is unity, while for a binomial distribution the ratio is less than one (indicating the variance is less than the mean), while for the negative binomial distribution, the ratio is greater than one. (The mean is what is usually called the "average," while the variance describes how spread out the data is.) In all data subsets, the variance-to-mean ratio was greater than one. This led Johnson and McCoy to test the data for fit to the negative binomial distribution. Out of thirty-six of these data subsets for the three IMU's, twenty-two were fit to the negative binomial, at a ninety-percent confidence level. The other subsets could not be fit to any distribution by the statistical analysis package used by Johnson and McCoy.

Johnson and McCoy recommended (1978: 48, 49) further tests of both the logarithmic Poisson distribution (which is a generalization of the Poisson) and the negative binomial distribution. However, they noted (1978: 7):

> "If the requirements computation were not sensitive to the differences in demand embodied in alternative probability distributions, significantly improved accuracy would not be expected. If the requirements computation were, however, sensitive to these differences, the magnitude of the change would indicate whether an improved technique would pay for itself in savings or whether its effect would warrant the costs associated with implementation."

F. IMPLICATIONS OF NON-POISSON FAILURES

In a Rand Corporation Working Note, Lu (1977: 2) noted that one feature of the marginal analysis method of computation (which is called the D029) is:

> "that it makes an explicit assumption that demand for spare parts . . . can be represented by a certain probability function. In this way, the uncertainty inherent in spares demand can be explicitly modeled. But results may depend on a particular assumption regarding the probability function.
>
> "In D029, it is assumed that the probability density function of demands for spares during a period for which the WRSK is designed to provide support is the Poisson distribution. It may be necessary to perform an empirical investigation to resolve this question. However, first, a parametric analysis should be undertaken to gain insight into the effect of incorrect specifications of the probability function."

The Working Note reported on the results of that parametric analysis. Four WRSKs were constructed for the A-7D, one based on the assumption of the Poisson distribution, the others based on the assumption of a negative binomial distribution.

The characteristics of the WRSK with a Poisson assumption and of the WRSKs with the negative binomial assumption are shown in Table I. There are three negative binomial WRSKs because, unlike the Poisson, which has one parameter, the average number of failures, the negative binomial has two parameters. A parameter is used to completely specify the shape or form of a distribution.

The WRSK based on the Poisson assumption was then evaluated to see how responsive it would be to a situation in which the demand distribution was in fact a negative binomial. The results are shown in Table II. As Lu concluded:

> "if the assumption about demand distribution is incorrect, the expected performance of the WRSK can be grossly overstated. The most serious practical implication of such a misspecification is that it could lead to understating WRSK requirements."

Another interesting conclusion of the Working Note was that the composition of the Poisson WRSK and of the Negative Binomial WRSK with variance-to-mean Ratio 2.5 were significantly different. See Table III. The conclusion of this comparison was (Lu, 1977: 9),

> "if we switch from the Poisson distribution to the negative binomial distribution, the stockage of more than half of the items would be affected. For a handful of high-cost and high-demand items, there will be a little less depth in the stockage, but for a large number of low-cost items, there will be an increased stockage. Thus, the compositions of the resulting kits are quite different. Implications of this difference require further investigation."

To reiterate, Lu concluded, (1979: 10)

> "First, we found that if we use the Poisson density function to approximate demands and it turns out that the demands follow a negative binomial distribution, then our estimates of the characteristics of a WRSK based on the Poisson assumption are too optimistic. Secondly, if a new kit were to be determined based on the negative binomial assumption,

TABLE I
CHARACTERISTICS OF A-7D WRSKS

	Poisson	Negative Binomial with Variance-to-Mean Ratio 1.5	2.0	2.5
Cost ($million)	4.97	4.99	4.95	4.91
Stock Outages	60.5	69.6	77.2	73.4
NORS (NMC Aircraft)	6.4	7.7	8.8	9.8

Source: Lu, 1977, Tables 2 and 3: 7, 8

TABLE II
PERFORMANCE OF A-7D POISSON WRSK
UNDER NEGATIVE BINOMIAL DEMAND

	Variance-to-Mean Ratio of Negative Binomial Demand 1.5	2.0	2.5
SDO	72.2	81.6	89.3
NORS	7.7	8.9	9.9

Source: Lu, 1977, Table 3: 8

TABLE III
DIFFERENCES IN DEPTH OF STOCKAGE OF
HIGH COST ITEMS
BETWEEN POISSON AND NEGATIVE BINOMIAL A-7D WRSKS

Item	Unit Cost	Poisson WRSK	2.5 Negative Binomial WRSK
RT Unit	$ 4,257	19	18
Receiver	5,302	20	17
Receiver	30,890	14	12
Processor	19,274	18	15
I M U	54,075	12	11
Computer	98,314	10	9
Display	33,472	15	13

Source; Lu, 1977, Table 4: 9

the composition of this new kit will be quite different from that of the original one.

"The above findings suggest that empirical investigation is needed to determine which probability density function will fit demand data better."

As a direct result of that conclusion, this study is an empirical investigation of failure distribution.

G. DISTINCTION BETWEEN FAILURES AND DEMANDS

It is worth noting at this point that there is a difference between failures and demands. At the depot level, there is virtually no distinction because, if an item which has not failed is removed from an airplane at the unit level, it is tested and returned to stock at the unit or base level, and never generates a demand at the depot level. However, at the unit or base level, the distinction between demands and failures is more significant. Several items may be removed from an airplane for testing and be replaced at once from the spares stock. This generates a local demand, but all of those removed parts which are not failures are checked out and returned to stock. Thus, only a portion of demands may be classified as true failures. Conversely, there may be failures which are not demands from an airplane. Items in stock are periodically tested, and a failure of one of these items will result in a demand on depot (or in a repair at the local level, if the item is locally reparable) without being the result of airplane operation, and thus having no functional relationship to flying hours, or sorties. Similarly, "hangar queens," airplanes which serve as sources for cannibalized parts and are only rarely flown, serve as a virtual extension of supply. A part may be removed from one of these airplanes and tested as non-operational. The failure of this part might be due to degradation, or to damage when other parts were removed from the airplane, but it can hardly be related to the operation of the source airplane.

What factors might influence failures in an airplane?

H. FACTORS INFLUENCING FAILURES

Bendle and Humble (1978) considered, from a theoretical point of view, four different aspects of operating history which might influence failure and degradation behavior. The four different aspects were: total elapsed calendar time, total accumulated "on" time, length of current operating history, and random environments. The unit was modeled as being capable of failing in any one of the first three modes, all operating independently of the others. The authors assumed a constant hazard rate in each of the first three modes, thus invoking once again the assumption of Poisson behavior. As in the case of devices connected in series, failure in any one mode caused failure of the unit. Degradation of the unit was a function of the first three modes plus random environment.

In this present study, the failure behavior is considered to be influenced by flying hours, which, for the airplane itself, corresponds approximately to accumulated "on" time. It is recognized that individual items of equipment may not be operated constantly while the airplane is in flight; an extreme example would be tires, which are stressed on landing and takeoff.

It has been shown empirically that other factors affect failure behavior. Tadashi (1975) showed that there were strong seasonal trends in the mean time to failure of the Air Data Computer, correlating (Tadashi, 1975: 98-99)

> "with a special training program for the Japanese Air Force: namely, a flying technical competition for each Air Force Base had been held regularly in the spring, and pilots tend to become more critical of equipment (Air Data Computer) operation having an impact on aircraft flight stability in a competition season. For this reason maintenance service men also become more critical of equipment performance during ground inspection."

Mean time to failure dropped in the spring, not as a result of the number of flying hours changing, but rather because of the circumstances under which the flights were occurring. This leads to the question, does failure behavior

in peacetime training accurately predict failure behavior under surge conditions or under wartime deployment? Does the length or frequency of sorties have an impact on the failure rate as a function of time? Hunsaker, Conway, and Doherty determined (1977:v) that:

> "the length of time for a sortie has little affect [sic] on the number of maintenance writeups following. Therefore, an increase in sorties for a given period with no change in flying hours would generate additional maintenance writeups."

They also noted (1977:v) that "some WUC's [Work Unit Codes] are sensitive to specific types of mission flown."

Therefore, it can be seen that the type of mission, the circumstances surrounding the mission, the attitude of maintenance personnel, and the length and frequency of mission may all effect the failure behavior of an item of equipment.

This study examines failures which result from aircraft operation.

I. OBJECTIVES OF THIS STUDY

The basic objectives of this study are:

I. Determine the probability distribution function(s) of peace-time failures resulting in demands from a WRSK.

II. Determine the probability distribution function(s) of surge failures resulting in demands from a WRSK.

III. Determine the relationship between peacetime failures and surge failures.

In order to accomplish these objectives, operational data will be examined.

J. REVIEW OF LITERATURE

1. Proshcan; Ascher and Feingold. There have been other studies of operational data which examined empirical failure distributions. One of the most well known of these is the study conducted by Proschan in 1963. Proschan

examined data from a fleet of thirteen airplanes on failure of an air conditioning system. The airplanes were all Boeing 720 jets, and the data covered an extended period of time.

Proschan's data and paper were extensively reviewed by Ascher and Feingold (1979). Both papers are discussed below.

Proschan's study had two major similarities to this study. First, "the original aim was to make predictions and decisions for the entire fleet of 720 jets (rather than for individual airplanes)," so Proschan pooled data from the airplanes as part of his preliminary analysis.

Second, the air conditioning system may be regarded as a reparable "black box" component with unknown subcomponents. It is worth noting here that the WRSK includes both reparable and non-reparable items, corresponding to the two maintenance concepts used by the Air Force: "remove and replace" ("RR"), and "remove, repair and replace" ("RRR").

The two concepts apply to components of the airplane known as LRUs, or Line Replacable Units. These units may be thought of as "black boxes" with unknown, undifferentiated contents. An LRU is removed from the airplane when there is an indication that the unit has failed, whether because the function which it should perform is not being accomplished, or because there is a system indication such as a warning light, or because of visible damage, or for any other reason.

Once an LRU is removed from the airplane, it is immediately replaced by a like item. This is the "remove and replace" part of both the RR and the RRR maintenance concepts. The item is then bench checked, that is, tested in a shop, to determine if it has in fact failed. If it has not failed, it is placed with the stock of replacements. Depending on the turnaround time in the shop, efficiency of the mechanics, and so on, it might even be immediately

reinstalled on the airplane it was removed from, but this cannot be assumed, and is not required. Rather, the unit is meant to be replaced at once.

Only after a failure has been verified, does the treatment of the LRU vary between the RR and the RRR maintenance concepts. In the RR concept no maintenance capability or spares are available to repair the LRU at the forward site. The LRU is either disposed of or returned to the rear support area or the next higher level of maintenance support for repair. Under the RRR concept, the items may be repaired at the deployed maintenance shop, and certain spare parts may be stocked. These parts are called Shop Replaceable Units, or SRU's, and may be regarded as the subcomponents of the black box which was removed from the airplane. One or more of these subcomponents may have failed or been damaged, causing the component, or LRU, to fail. SRUs may also be reparable, and are also classified as either RR or RRR items. In their discussion of Proschan's paper, Ascher and Feingold made a strong distinction between repairable and non-repairable systems. The distinction develops from two commonly used meanings of "failure rate." One of these meanings represents whether or not there is an increasing or decreasing tendency for an item to fail the longer it is used. Ascher and Feingold preferred the term "force of mortality" for this concept. It is also sometimes called the "hazard rate." The other meaning is the tendency of successive items in the same system to have progressively longer or shorter lives, which might be the result of system deterioration or improvement. Ascher and Feingold illustrated this distinction with the following example (1979: 154):

> "Assume that a sequence of light bulbs are placed in a socket, each replacing the previously burned out bulb. Assume further that each bulb wears out, i.e., the longer it operates, the more likely it is to fail in the next unit interval . . . . However, further assume that the successive bulbs have longer and longer lives, ... Under these assumptions, the times between successive failures will tend to become larger and larger in spite of the increasing force of mortality within

each failure interval. If the usual terminology were used to describe this situation, a statement such as the following would have to be made: the overall 'failure rate' is decreasing even though the 'failure rate' within each interval is increasing."

Ascher and Feingold thus distinguished between wearout of a reparable and of a non-repairable item (1979: 154-155):

"For non-repairable items, the relationship of increasing force of mortality to wearout is straight-forward: the older the unit (as measured from the time it was first put into service) the greater the chance that failure will occur in the next unit of time. For a repairable item, however, wearout in the sense of increasing force of mortality is a property of an interval between successive failures. This follows from the fact that the 'age' associated with force of mortality is the time since last repair instead of the time since the system was first put into service. Therefore, aging in the different sense, that times between successive failure of a repairable system are getting smaller, should be referred to by another term, e.g., 'deterioration'."

As a consequence of the distinction they draw between repairable and non-repairable systems, Ascher and Feingold conclude (1979: 158),

"even when the homogeneous Poisson Process is the appropriate model for a repairable system, this model is not equivalent to an exponential distribution used as a model for a nonrepairable item."

In Proschan's study, the air conditioning system would be a repairable item, for which the Poisson Process is an appropriate model. In this study, generally, an RR item would be a nonrepairable item, for which the Poisson Process would not be appropriate. However, no strict correlation can be made between RRR and repairable in the sense of the distinction in question; apparently the air conditioners in the Proschan study were identified with a particular airplane, whereas RRR units will not necessarily be returned to the same airplane from which they were removed. They must be assumed to be "good-as-new" in whichever plane they are returned to.

This assumption of "good-as-new" does not, however, correspond to an assumption of "independent but identically distributed," as Ascher and Feingold imply. The WRSK components fall into an intermediate category between the air conditioner systems and the transistors Ascher and Feingold offer as

alternatives. The WRSK components will be treated here as if an exponential model were equivalent to a homogeneous Poisson process (and analogously, as if the Bain-Wright distribution were equivalent to the Negative Binomial process).

Proschan studied the distribution of failure intervals, rather than the distribution of the number of failures in a given time interval. That is, he was working in the continuous, rather than in the discrete mode. His test for an exponential fit of the failure intervals has implications for the distribution of the number of failures in a given time interval, since he was definitely working in a situation where the exponential model was equivalent to the Poisson process.

Proschan first pooled all the interarrival times and computed their mean. By the Maximum Likelihood Estimator, if the data fit an exponential distribution, that mean would be its parameter. Using the Kolmogorov-Smirnov test, he tested the exponential distribution (with its parameter estimated from the data) against the data. Although he was unable to reject the exponential distribution, he concluded that the fit was not good, because his data crossed the theoretical line only once. That is analogous to comparing data against a straight line, and finding that, although there is not a statistical rejection, the data is all below the line to a certain point, and then all above it. The indication is that the data would better fit a line with a different slope.

Proschan then tested the data for each individual airplane to see whether successive intervals between failures would show a trend. He used the Mann nonparametric test against trend for individual airplanes, then pooled the data using the Fisher procedure, and again found no significant evidence of trend. He therefore concluded (Proschan, 1963: 180) that, "it would be appropriate to consider the successive intervals between failures for a single

airplane to be governed by a single probability distribution." His next step was to test whether the distribution of intervals between failures was exponential for each plane. He performed the Proschan-Pyke test, ranking and normalizing the intervals for each plane, then pooling the data for the different airplanes (Proschan, 1963: 381),

> "without necessarily assuming that the failure intervals for different planes have identical distributions; rather . . . that each plane has a constant failure rate (equivalent to the assumption of an exponential distribution), the constant being different for the different airplanes."

His conclusion from this was that (1963: 381),

> "no conclusive evidence exists that the intervals between failures for the individual airplanes have increasing failure rates rather than constant failure rates. Putting it more positively, it seems safe to accept the exponential distribution as describing the failure interval, although to each plane may correspond a different failure rate."

Ascher and Feingold pointed out (1979: 156) that it would have been inappropriate to perform the Proschan-Pyke test if it had not already been demonstrated by the Mann test that there was no trend in the data, and that therefore the data could be assumed to be IID (independent and identically distributed).

In the final section of his paper, Proschan discussed whether the different planes had different failure rates. He pooled the failure intervals from all the planes, applied the Proschan-Pyke test, and concluded, "the pooled distribution has a decreasing failure rate, as would be expected if the individual airplanes each displayed a different constant failure rate."

2. Bain and Wright. Recently, Proschan's data was reexamined by Bain and Wright (1981) who used it to illustrate the continuous interarrival distribution for the negative binomial distribution. The analysis assumed that each plane had an individual constant failure rate, and that the failure rates were distributed according to the gamma distribution. Using those airplanes with at least 1000 flying hours, Bain and Wright estimated the average

intensity (that is, the average of the individual constant failure rates) and was able to calculate the reliability of an air conditioner, and the number of spares required to be 95% certain of completing 100 flying hours.

3. Fiorentino. Fiorentino (1979) generally followed Proschan's procedure with failure intervals from ground electronic systems. First, however, he plotted cumulative failures against cumulative operating time for each of the twelve equipments he was testing. In some cases, the resulting curve was concave upward, and in some cases concave downward, but in most cases there was no clear indication of reliability change.

Fiorentino applied the Mann test for trend to each of the equipments he was working with. He then applied a goodness-of-fit test for exponentiality, and accepted the exponential for nine of the twelve cases. Finally, he graphed the fitted reliability function against the empirical data, as Proschan did. One of his equipments crossed the theoretical line only once from above, but his pooled data fit the theoretical line very well.

4. Other Studies of Operational Data. Other studies of operational data include a case history by Tadashi (1976) of a mechanical, rather than an electrical device. Seventy-three percent of the removals over a seven year period were due to preventive maintenance. The average time between overhauls was about 400 hours. The removal time followed a Weibull plot, with a change in the shape parameter at 45 hours, after which the Weibull approximated an exponential.

Another example of development of an empirical failure distribution is found in Bilikam and Moore (1977). Data regarding aircraft and missile failures was considered to be grouped because it was known within what time span the equipment failed (during the mission) but not at what precise time the failure occurred. This is precisely analogous to the information available about the WRSK components. Bilikam and Moore developed Maximum Likelihood

Estimators for these data, assuming a 2-parameter Weibull distribution, and also for the exponential distribution.

In a sequel to the above paper, Bilikam and Moore (1978) examined failure data on one type of aircraft engine component, as well as operational intervals for equipment which did not fail. Since, in this case, the actual failure times were known, the data were treated differently. Maximum likelihood estimators were obtained, and used to generate a simulation for both the exponential and Weibull models. The authors did not make any decision as to which was more accurate.

Rather than determining the distribution for failure of parts of an aircraft, Cockburn (1973) developed methods for modeling the failure times of an entire aircraft from data which gave the mission duration and functional status of the aircraft at the end of the mission. The data were grouped by mission duration, and were considered to be censored. Two models were considered for the distribution: the Weibull, and the exponential, which may be considered a special case of the Weibull. As Cockburn pointed out (1973: 13),

> "the Weibull distribution is an appropriate model whenever the system is composed of a large number of components and failure is essentially due to the most severe flaw among a large number of flaws."

Several estimation methods were used to develop the parameters for the model. Maximum likelihood estimates were used as well. These parameters were used to estimate the probability that the equipment would survive a mission of specific duration.

The negative binomial distribution has been suggested elsewhere as a possible demand distribution. Mitchell (1976) investigated the use of bivariate distributions in aircraft logistical problems:

> "Applications of bivariate distributions to certain aircraft logistical problems are investigated. Primarily, a bivariate negative binomial distribution is filled to spare parts demand data in two periods and to

monthly abort data on either side of a large scale maintenance event and it is shown how the associated sample distributions can be useful in parts inventory control and investigating the effect of maintenance on an aircraft's performance."

In order to gather operational data, the present investigators studied F111D airplanes at Cannon Air Force Base.

II. METHOD

A. OVERVIEW OF RESEARCH DESIGN AND METHODS USED

Data regarding maintenance actions on selected aircraft components were gathered from Cannon Air Force Base, New Mexico. Data regarding the flying hours of aircraft at Cannon were also gathered. The maintenance data were screened to eliminate records of questionable accuracy, and to identify failures of the aircraft components. The failure and flight records were then merged to provide statistics such as interfailure intervals, number of failures in a given period of time, and so on. These statistics were then analyzed and compared with the theoretical Poisson process and with the negative binomial process in an effort to establish the best fit for each component. The data were then sorted by date and aircraft into sets stressed by surge and unstressed by surge. These sets were then compared through the same sorts of analysis as above.

B. DATA COLLECTION

In order to draw meaningful conclusions from maintenance data, there must be an adequate amount of reliable, relevant information. There have been previous attempts to use maintenance records to develop failure and reliability descriptions, only to find the information either sparse, dirty (that is, unreliable--"pencil magic"), or simply irrelevant to the question at hand.

As Vesely and Merren point out (1976: 158), "data collection in itself is of no particular value. The payoff comes from extracting the proper information from data." In some cases, extracting the proper information is extremely difficult.

In an attempt to derive reliability and maintainability parameters from Navy R & M data, Klivans (1977) broke the derivable parameters into four classes:

1. MTBMA (mean time between maintenance actions)
2. MTBR (mean time between removals)
3. MTBVF (mean time between verified failures)
4. MTBMEF (mean time between mission-essential failures)

Note that Klivans is working with mean times between events--that is, whether explicitly or not, with the Poisson process.

> "The specification requires that reliability be demonstrated by measuring the mean time between mission-essential failures (MTBMEF) in a fleet operating environment. The MTBMEF is based on those failures that would abort or appreciably degrade . . . system performance in any of its missions. . . .
>
> "The Navy R & M data available from carrier deployment are not detailed enough to calculate MTBMEF. Therefore, to ensure that MTBMEF could be derived, a control data source was established at Miramar NAS for operational system usage." (Klivans, 1977: 27)

It was necessary for Klivans to use data other than those obtained under ordinary operational and maintenance recording procedures. In this present study, the aim was to use records collected under normal operating conditions as the source of data.

The source of the maintenance data used in this study is the Maintenance Data Collection System. The MDC system was designed primarily as a base level maintenance management system. The objectives of the system are to provide maintenance managers with information on the maintenance accomplished by assigned personnel, to identify the reasons why the work was required, and the actions required to complete the maintenance job. All maintenance actions involving direct labor expenditure such as scheduled inspection, preventive maintenance, and unscheduled maintenance, both on-line and off-line, are reported in the MDC system.

The determination of a failure distribution is currently based on the repeated failure of an item over time measured in flying hours. Data on aircraft operations are collected through the Maintenance Management Information and Control System (MMICS). These systems are merged to provide an average. Given that X failures in a certain item (identified by WUC, Work Unit Code) occurred in a time period such as three months, during which time Y flying hours were generated at the same activity center, the mean time between failures can be calculated as X/Y. This procedure masks any difference among airplanes, any trends, and the influence of surge or sortie length variations. Unfortunately, the mean time between failures obtained cannot even be considered to provide a mean time between verified failures. The accuracy of the maintenance data is extremely suspect. In his study of maintenance information about ground electronic systems Fiorentino (1979: 71)) noted,

> "the Air Force field technician is primarily motivated to 'fix' the equipment and not to isolate failure causes. As a result, the field data tend to reflect replacement actions which were performed to facilitate the repair rather than specifics regarding the cause of failure."

The following problems were noted with field maintenance data in that study (Fiorentino, 1979: 21-22):

> "Both the AFM 66-1 and AFM 65-110 data records were incomplete. For example, it was possible to match the Job Control Number (66-1 data) with the Equipment Status Report Numbers (65-110) in only 54% of the total reported malfunctions. In addition, some of the malfunctions involved multiple board or part replacements without any indication of which board or part was the primary cause of failure. In other instances, a single board replacement was indicated in the data without any follow-on part failures or replacements. It was also found that some of the failures were in redundant channels, and did not cause system outages or were in associated test equipment. Other malfunctions listed in the data were discovered during the performance of daily or phased inspections for which the equipment is taken down on a scheduled basis.
>
> "Lastly, some apparent malfunctions were linked with extensive troubleshooting times, but with no subsequent repair or replacement actions."

Similar problems were expected in gathering data for this study. Major emphasis was put on developing criteria to screen the maintenance data in order to provide a reliable verified failure. Theoretically, it should be possible to identify mission-essential failures based on the presence or absence of an abort code; however, not all WRSK items are mission-essential, so it was not within the scope of this study to carry the screening procedure that far.

C. SELECTION OF SUBJECTS

1. Selection of Aircraft. The data were gathered from Cannon Air Force Base, New Mexico. Cannon is the home of the 27th Tactical Fighter Wing, made up of F111D aircraft. All F111Ds which had records of flight operations and maintenance actions still on file at Cannon were subjects of this study, though the inventory actually at Cannon changes over time due to depot level overhaul and other reasons.

2. Selection of Aircraft Components. For maintenance purposes, airplane systems, subsystems, components, and subcomponents are identified by symbols called Work Unit Codes. A Work Unit Code (WUC) is a five-character, alpha-numeric symbol, which identifies the item on which the maintenance action was performed. The first two digits of the symbol identify the major system in the airplane, the third identified the sub-system within the specified system, and, in general, the fourth digit identifies the component and the fifth the subcomponent (see Figure 1). In the figure, WUC 73000 refers to the Bombing Navigation system; 73H00 refers to the Navigational Set, Inertial, subsystem; 73HC0 refers to the Navigational Computer Unit component; and 73HCB refers to the Network, Input-output, No. 1, subcomponent.

Work Unit Codes to be studied were selected in the following manner:

First, the WRSK list for the F111D was examined, and all EOQ (economic order quantity) items were eliminated from consideration.

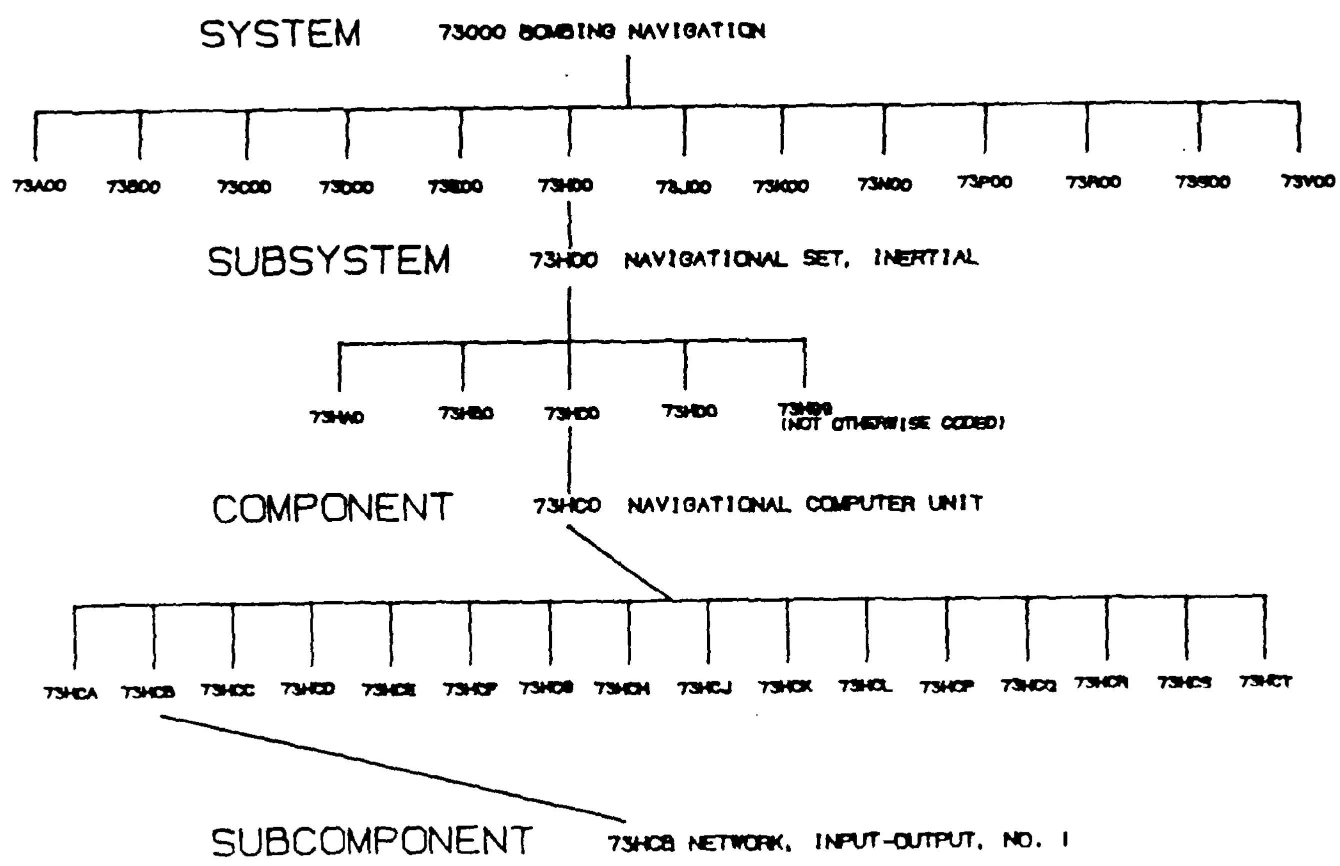

Figure 1. Work Unit Code Hierarchy

Next, in order to simplify the data gathering, all items listed with a QPA (quantity per application, or number of items on the airplane) greater than one were eliminated.

Of the remaining WUCs in the WRSK, those with the largest apparent failure rate, according to the worldwide depot demand rate, were referenced in the technical manual for the F111D. There were only two years of data available, and items with low failure rates might not fail often enough in those two years to be analyzed. Also, each run of the data extraction program could only accommodate 150 WUCs, and it was desired to minimize the number of runs, while obtaining the maximum possible amount of data.

If the WRSK item was a component, and had a WUC in the form XXXX0, such as 73HC0, then 73HC0, and all its subcomponents were included in the extraction list. In this case, 73HC0, 73HCA, 73HCB, 73HCC, 73HCD, 73HCE, 73HCF, 73HCG, 73HCH, 73HCJ, 73HCK, 73HCL, 73HCP, 73HCQ, 73HCR, 73HCS, and 73HCT would all have been included in the extraction list.

On the other hand, if the WRSK item was a subcomponent, with a WUC in the form XXXXA, such as 73HCB, then 73HCB and its parent component, 73CH0 would have been included in the extraction list. The parent WUC must be included to extract data about the subcomponent.

The resulting list of over 300 WUCs was increased to total 450 by including some WUCs with apparently low failure rates. 450 WUCs required three runs of the extraction program at Cannon.

3. Extraction of Data. The data required were obtained directly from MDCS and MMICS at the base level through the use of two programs developed by the Design Data Center at Gunter Air Force Base and one developed by the Logistics Center at Wright-Patterson Air Force Base. See Appendix II. Two of the programs extracted flight data, and one program extracted maintenance data. Two programs were necessary for the flight data because "current" and

"historical" flight information were stored in different formats. The data extracted were the same, however. The maintenance information which the extraction program NBDQ99 extracted included the following:

1. The Mission Design Series of the airplane, in this case F111D.
2. The airplane's "Tail Number," or serial number.
3. The Job Control Number. The first three digits are the Julian day the Job was initiated; the last four digits are a unique identifier for work begun on that day.
4. Station location code: identifies the Base; in this case, Cannon.
5. The Work Unit Code.
6. The Action Taken Code, indicating, e.g., removal, failure, etc.
7. When discovered: a code telling when the malfunction was discovered
8. The year.
9. The stop day. The Julian data of completion of the action reported in this entry, but not necessarily the final action under this job Control Number.

The flight information which the programs NRFRMC and NFBRAA extracted included the following:

1. The tail number of the plane.
2. The Julian date of the flight.
3. The total number of hours flown on this date.
4. The total number of landings on this date.
5. The total number of sorties on this date.
6. The total number of full stops on this date.
7. The identity of the unit owning the plane.

D. DETECTION AND REMOVAL OF ERRORS IN THE MAINTENANCE DATA

1. Introduction. The effort to purify the data from the MDCS was concentrated on three possible sources of error: sloppy recordskeeping,

typographic error, and the problem of the "orphan part." Eradication of "false" failures rather than retention of historically true failures received priority.

The computer program which screened the MDCS data is called the MAINTLOG program. It was developed at the Computer Center of the University of Missouri-Rolla. See Appendix III.

In order to verify a failure, MAINTLOG required at least two Action Taken entries--at least one removal/replacement action, and at least one shop action indicating a failure had occurred.

Table IV lists the Action Taken Codes accepted by MAINTLOG in each category.

2. Sloppy Records. It must be reemphasized that, while mechanics generally appreciate the equipment they work on, and enjoy fixing it, the same enthusiasm, thoroughness, and intensity of effort is not apparent in filling out required paperwork. Unlike supply personnel, who have a vested interest in filling out their forms properly (the items they have ordered come in) maintenance personnel do not receive any similar benefits as a natural consequence of paperwork. On the contrary, paperwork provides a disincentive in the time that is lost in filling it out, which might (it would seem to a mechanic) more productively be spent in fixing something.

Further, it is not always possible to complete maintenance records as the work is being done. They must be filled out after the fact, from memory.

It is not surprising, then, that there is some mistrust of the accuracy of the maintenance records. This mistrust is particularly understandable when considering those statistics likely to be padded--length of time spent on a job by the mechanic, and so on. However, the aim of this study is to isolate equipment failures. The verification process in large part consists of ensuring that some work was actually done on the part in question, and that the

TABLE IV

ACTION TAKEN CODES ACCEPTED BY MAINTLOG

	Code	Action Description
Removal/	P	Removal
Replacement	R	Remove and replace
	Q	Installed
	A	Bench checked and repaired
Failure	C	Bench checked--repair deferred
	D	Bench checked--transferred to another base or unit
	1 through 9	Bench checked but not repairable at the reporting station, returned to depot, or condemned
	F	Repair
	G	Repair and/or replacement of minor parts, hardware, and softgoods

item removed from the aircraft did receive some shop action afterwards which indicated it had failed. By requiring two actions, the chance of accepting a WUC which had been entered in lieu of coffee break is reduced. This confirmation process has other benefits also, as will be discussed below.

3. Typographic Errors. Any unrepeated typographic error in the Airplane Tail Number or in the Job Control Number causes the entry to be discarded because of the MAINTLOG requirement for at least two entries.

Discarding an entry with a typographic error does not necessarily result in the loss of the entry recorded. Entries are frequently duplicated in the MDCS records (possibly two mechanics working the same plane have both reported the same action), and the information lost with a typographic error might well be retained in a duplicate entry.

Repeated typographic errors in the airplane tail number would have no effect as long as the new tail number does not mimic an actual tail number; with no flight data recorded under the erroneous tail number, failures recorded under that number would not generate a failure interval.

The Job Control Number is composed of two segments: the Julian date on which the Job Control Number was assigned, and the sequence number (which may encode administrative information). As mentioned above, an unrepeated error in the Job Control Number is discarded. In an actual example of this sort of error, a series of 29 entries under JCN 0363055 was followed by 0363059 and then 0366305. In the first case, a nine was entered instead of a five; in the second case the six was entered twice, which shifted the other digits over. MAINTLOG would discard the last two entries, but it would also report the failure based on the first 29 records.

A repeated typographic error in the sequence number of the JCN may result in loss of a true failure (if the shop action code and the removal/replacement code are recorded under two different Job Control Numbers), or in a report of

a failure under an incorrect JCN (if the shop action code and the removal/replacement code are recorded under the incorrect JCN), or in a multiple record of a single failure (if several of the maintenance actions had been recorded more than once, a shop action code and removal/replacement code may have been reported under both the correct and the incorrect JCN).

A repeated error in the Julian date of the JCN will distort the reported flying hours between failures, unless the recorded Julian date is outside the period of analysis. In that case the failure is lost.

4. "Orphan Parts." When a part is removed from an airplane for shop testing, a tag is placed on it. The tag connects the part to its source airplane. If the tag were lost or torn off, the part could not be traced back to its source airplane. Other parts may be in the shop which came out of base stock. There are periodic checks of base stocks to ensure no deterioration during storage.

In order to confirm that the part whose shop action was recorded was actually removed from the airplane it was recorded under, an Action Taken Code showing either removal, removal and replacement, or installation of the part on the same airplane under the same Job Control Number is required. If a higher level part, such as the subsystem containing the failed component, or the subsystem or component containing the failed subcomponent, had a recorded removal or replacement action, the MAINTLOG requirement is satisfied.

E. MERGING MAINTENANCE AND FLYING INFORMATION

The data obtained from the MMICS and MDCS systems must be merged in order to obtain information about failures as a function of flying hours. The calendar dates of verified failures, taken from the Julian date of the Job Control Number, are used as boundaries for the summation of information from the flying data. All flying hours recorded for the airplane in question, between the boundary dates, are summed up to provide the time between failures of the

WUC which failed on the two boundary dates. If the plane flew on one or both of the boundary dates, failure was arbitrarily assumed to have occurred at the midpoint of that day's flying hours, otherwise it was assumed that the failure occurred at the completion of the last flight before the failure. The times between failure resulting, then, must be considered to be grouped, because the exact moment of failure is unknown. The data as a whole must be considered to be censored, because failures of each WUC were not recorded on each plane, and some long times to failure may have been lost as a result.

F. PROCEDURE FOR ANALYSIS OF MAINTENANCE DATA FROM ANALOG EQUIPMENT

The F111D airplane is a digital system. Other airplanes in the Air force inventory, such as the F4, are analog systems. Certain aspects of the analysis of maintenance data for an analog system must be handled differently than for a digital system. For example, most subcomponents in the F4 are shop removable items rather than line removable items. Since removal/replacement actions are recorded only for equipment on line, that is, on the airplane, removals are not entered for shop removable subcomponents of the F4. In order to verify the origin of the subcomponent, a removal of the parent component must be on record.

A digital system has a much greater capability than an analog system for built in testing. Built in testing (BIT) refers to testing equipment in place on the airplane, rather than taking it to the shop for testing in a mockup. This advantage is due to the degree of degradation of signal in the system required to cause failure. In an analog system, a ten percent error in an input signal results in a ten percent error in the output. A small degradation in each of a series of items may result in a serious distortion of output. In contrast, digital equipment is a go/no go technology. If the input signal is within a range of acceptable values, it is adjusted to the target value. If there were a ten percent error in each of a series of items, the error in

input signal to each item would be corrected. An error outside of the acceptable range would result in no output signal at all. Thus, it is much easier to identify and correct faulty equipment in a digital system than in an analog system.

The effect of this difference in technology means that when an item is removed from a digital system, there is a strong indication that it has failed, and not an associated piece of equipment. In contrast, many items may be removed from an analog system for testing in the shop as a result of one suspected failure. It is here assumed that when several components are removed from the same analog subsystem for preliminary testing, not all the removals may be recorded. Therefore, it is assumed that a shop action indicating failure may be verifiable by a removal/replacement action on a related component or subsystem. The degree of relationship desired may be entered as a parameter to MAINTLOG.

Notice that a WUC has five characters. If a parameter of "5" is entered to MAINTLOG, the analysis will require a removal/replacement action on the subcomponent in question itself, or on its parent component or subsystem. This is the procedure that is followed for a digital system such as the F111.

A parameter of "4" may also be entered. In this case, the first four characters of the Work Unit Code are considered to be significant. If there is a removal shown on any item with the first four characters, for example, 73HC, that removal is considered to validate the failure of any item with those same first four digits which has a shop action code indicating failure. It should be noted that the results with a parameter of 4 entered should be the same as with a parameter of 5, because there should be no removal/replacement codes for shop removable units, and most subcomponents in an analog system are shop removable.

A parameter of "3" may also be entered to MAINTLOG. The first three digits of the Work Unit Code are considered to be significant. If there is a removal/replacement action shown on any item which has, for example, the first three characters 73H, that action is considered to validate the failure of any item with those same first three digits. In practice, this means an assumption that if any part of the subsystem was removed from the airplane, any other part of the subsystem may also be assumed to have been removed.

It is recommended that this capability of MAINTLOG be reserved for the analysis of analog systems, after discussion with personnel familiar with the procedures followed by maintenance workers. It must be based on a reasonable assessment that not all removals are recorded properly, and that the only realistic way to capture true failures from the maintenance records is to relax the validation requirements.

For digital equipment, a parameter of "5" should be used.

III. RESULTS

A. DATA OBTAINED

1. Introduction. Seven thousand and fifty-eight flying records, covering seventy-six airplanes from July 1979 to September 1980, were obtained from Cannon. Merging these records with the maintenance data produced 1146 intervals between verified failures of forty-one WUC's on seventy-five airplanes. The 46 planes which flew at least 200 hours showed 1026 verified failures on 58 WUCs in their first 200 hours, while the 14 planes which flew at least 300 hours showed 323 verified failures on 43 WUCs in their first 300 hours.

2. Interfailure Intervals. Table V shows how many failure intervals were obtained for each Work Unit Code which had any. The table also gives the worldwide mean time between failures for the WUC. This figure was calculated from the total demand rate, which is in units per hundred flying hours. The source of the total demand rate figure is the D029 Product List. For example, for WUC 51ABN, the total demand rate was 0.3333, giving a worldwide mean time between failures of 300.00.

Although the correlation is not exact, it can be seen that for those items with a reasonably short world mean time between failures the data obtained were much denser. This is not unreasonable; for a failure interval to be found, there must be at least two failures; if the failures are relatively rare events, there may not have been a long enough record of flying hours on any one plane for two failures to occur. Of the seventy-six airplanes on which flying records were obtained, only forty-six had over two hundred flying hours for the period covered. Items with worldwide mean times between failures of several hundred flying hours would naturally have very few failure intervals show up in this data.

Of the forty-one WUC's listed in Table V, seventeen had more than ten

TABLE V
WORK UNIT CODES
WITH AT LEAST ONE FAILURE INTERVAL

WUC	Worldwide Mean Times Between Failures (Flying Hours)	Number of Intervals	No. of Planes	Notes
13CDA	1767	3	3	
13ECA	2096	1	1	
13ECB	2577	1	1	
14BCA	1013	1	1	
14BCD	1202	1	1	
14BCE	901	1	1	
16CAC	826	2	1	
44AAH	119	1	1	
44AAJ	132	1	1	
51ABA	699	1	1	
51ABE	445	20	14	1
51ABH	303	12	7	1
51ABL	584	1	1	
51ABN	300	10	8	
51CAC	235	17	16	1
61AA0	150	36	28	1
61AB0	(153;842)129	22	16	1 & 2
61AC0	(11494;168)166	21	19	1 & 2

TABLE V (Continued)

WUC	Worldwide Mean Times Between Failures (Flying Hours)	Number of Intervals	No. of Planes	Notes
61BA0	332	11	10	1
61BC0	1163	[illegible]	[illegible]	
65AA0	231	6	[illegible]	
65BA0	102	23	19	1
65BC0	111	4	4	
65BD0	167	2	[illegible]	
71CA0	1637	6	7	
71CB0	1319	3	3	
71ZC0	2062	4	4	
73KD0	787	1	1	
73KG0	988	2	2	
73KM0	685	3	3	
73NA0	43	134	58	1
73NB0	307	4	3	
73PA0		94	49	1 & 3
73PB0	43	122	58	1
73PD0	43	167	57	1
73PP0		7	7	1 & 3
73QA0	157	13	[illegible]	1

TABLE V (Continued)

WUC	Worldwide Mean Times Between Failures (Flying Hours)	Number of Intervals	No. of Planes	Notes
73RB0	69	117	46	1
73RE0	28	219	66	1
73SB0	176	27	21	1
73SD0	208	20	17	1

Notes:

1 - Plotted

2 - Two Items

3 - Not on WRSK list: no world mean available

interfailure intervals. These were selected for further analysis in the continuous domain.

Items 61AB0 and 61AC0 were listed twice in the D029 Product List, with two different national stock numbers, two different nomenclatures, two different prices, and two different total demand rates each. The figures in Table V for these WUC's give in parentheses the individual times between failure for each listing. Table V also gives the time between failure which would correspond to the sum of the two demand rates.

Items 73PA0 and 73PP0 were not on the D029 Product List, and thus no total demand rate was available. These WUC's were included in the extraction list because some of their subcomponents are in the WRSK.

3. Failures. Recall that, in the discrete domain, the information analyzed is the event count, rather than the length of the interval between events. A constant length of time, ℓ, must be selected as a basis for comparison. In this case, two lengths of time were selected for analysis. First, two hundred hours was selected, and the number of failures occurring during the first two hundred flying hours of each plane which had two hundred flying hours was obtained. Those planes which did not fly at least two hundred hours were not considered. This means that some information was lost, but some information was also gained: cases with no failures or with only one failure are now included in the analysis. Next, three hundred hours was selected, and the number of failures occurring during the first three hundred flying hours of those planes which flew at least three hundred hours was obtained. Those planes which did not fly at least three hundred hours were not now considered. The reason for analyzing the data for both two hundred and three hundred hours was the striking difference in depth and breadth of data obtained.

Table VI, for two hundred hours, gives the mean and variance of the number of failures obtained on each plane for each WUC, as well as the total number of failures over all planes, and the maximum number of failures any plane showed for that WUC. For every WUC the minimum was 0, which means that for every WUC at least one plane did not show a failure in two hundred flying hours.

Table VII gives the same information for three hundred hours: the mean and variance of the number of failures, as well as the sum, the maximum, and the minimum number of failures shown on a plane. For every WUC except 73REO the minimum count was 0; for 73REO it was 2, indicating every one of the 14 planes had at least two failures of 73REO.

B. ANALYSIS OF INTERFAILURE INTERVALS

The procedures followed in examining the interfailure intervals is a graphic technique, following Proschan (1963), the second is a statistical test of exponentiality.

The times between failures from each airplane were pooled (that is, considered as a group), and the fraction surviving was calculated, and plotted against interval length.

Consider the following example:

Suppose three airplanes had the following failure intervals on item XXXXO: the first plane had a thirty hour interval, the second plane had a fifteen hour interval and a five hour interval, and the third plane had intervals of fifteen and fifty hours.

Imagine that instead of three airplanes, the five operating units represented by the failure intervals all ran at the same time, with their intervals starting at the same moment.

Up to five hours, all five units would be operating, which would be a fraction surviving of 100%. At five hours, one of the units (from the second

TABLE VI
FAILURE COUNT STATISTICS FOR FIRST
200 HOURS OF PLANES THAT FLEW AT LEAST
200 HOURS

WUC	Mean ($\bar{x}$)	Variance (s^2)	Max	Sum
13AAA	0.06541739	0.06231884	1	[illegible]
13BCA	0.04347826	0.04251208	1	[illegible]
13BCB	0.04347826	0.04251208	1	2
13BCC	0.02173913	0.02173913	1	1
13CDA	0.08695652	0.12560386	2	4
13ECA	0.08695652	0.08115942	1	4
13HCB	0.04347826	0.04251208	1	2
14BCA	0.06521739	0.06231884	1	3
14BCD	0.08695652	0.08115942	1	4
14BCE	0.04347826	0.04251208	1	2
16CAC	0.10869565	0.14347826	2	5
44AAH	0.06521739	0.06231884	1	3
44AAJ	0.06521739	0.06231884	1	3
46DAA	0.02173913	0.02173913	1	1
49BAA	0.02173913	0.02173913	1	1
51ABA	0.10869565	0.09903382	1	5
51ABD	0.04347826	0.04251208	1	2
51ABE	0.43478261	0.65120773	3	20
51ABH	0.26086957	0.37487923	3	12
51ABL	0.08695652	0.08115942	1	4

TABLE VI (Continued)

WUC	Mean ($\bar{x}$)	Variance (s^2)	Max	Sum
51ABN	0.30434783	0.39420290	2	14
51ABQ	0.02173913	0.02173913	1	1
51CAA	0.08695652	0.08115942	1	4
51CAC	0.41304348	0.29227053	2	19
61AA0	0.67391304	0.75797101	4	31
61AB0	0.54347826	0.65362319	3	25
61AC0	0.47826087	0.43285024	2	22
61BA0	0.32608696	0.31352657	2	15
61BB0	0.04347826	0.04251208	1	2
61BC0	0.15217391	0.17632850	2	7
65AA0	0.23913043	0.18599034	1	11
65BA0	0.56521739	0.42898551	2	26
65BC0	0.21739130	0.21835749	2	10
65BD0	0.10869565	0.09903382	1	5
71CA0	0.19565217	0.42753623	3	9
71CB0	0.17391304	0.19130435	2	8
71D00	0.02173913	0.02173913	1	1
71ZA0	0.06521739	0.06231884	1	3
71ZB0	0.06521739	0.06231884	1	3
71ZC0	0.15217391	0.13188406	1	7
71ZD0	0.02173913	0.02173913	1	1
73ET0	0.04347826	0.04251208	1	2

TABLE VI (Continued)

WUC	Mean ($\bar{x}$)	Variance (s^2)	Max	Sum
73KD0	0.08695652	0.08115942	1	4
73KM0	0.15217391	0.17632850	2	7
73NA0	1.91304348	2.92560386	7	88
73NB0	0.26086957	0.24154589	2	12
73PA0	1.69565217	1.46086957	4	78
73PB0	2.06521739	2.64009662	6	95
73PD0	2.52173913	4.52173913	10	116
73PPD	0.06521739	0.06231884	1	3
73PP0	0.26086957	0.24154589	2	12
73QA0	0.23913043	0.23043478	2	11
73RB0	1.69565217	2.74975845	9	78
73RE0	3.47826087	4.21062802	9	160
73SB0	0.54347826	0.74251208	4	25
73SD0	0.34782609	0.27632850	2	16
73SF0	0.10869565	0.09903382	1	5
75BAK	0.15217391	0.13188406	1	7

TABLE VII
FAILURE COUNT STATISTICS FOR FIRST
300 HOURS OF PLANES WHICH FLEW AT LEAST 300 HOURS

WUC	Mean ($\bar{x}$)	Variance (s^2)	Max	Sum
13BCB	0.07142857	0.07142857	1	1
13ECA	0.07142857	0.07142857	1	1
14BCA	0.07142857	0.07142857	1	1
14BCD	0.07142857	0.07142857	1	1
16CAC	0.07142857	0.07142857	1	1
44AAH	0.14285714	0.13186813	1	2
44AAJ	0.07142857	0.07142857	1	1
49BAA	0.14285714	0.13186813	1	2
51ABE	0.07142857	0.07142857	1	1
51ABH	0.50000000	0.57692308	2	7
51ABN	0.28571429	0.37362637	2	4
51ABQ	0.14285714	0.13186813	1	2
51CAC	0.57142857	0.57142857	2	8
61AAQ	0.78571429	0.48901099	2	11
61AB0	0.71428571	1.14285714	3	10
61AC0	0.50000000	0.57692308	2	7
61BA0	0.28571429	0.21978022	1	4
61BC0	0.14285714	0.28571429	2	2
65AA0	0.21428571	0.18131868	1	3
65BA0	0.85714286	1.20879121	3	12
65BC0	0.14285714	0.13186813	1	2

Table VII (Continued)

WUC	Mean ($\bar{x}$)	Variance (s^2)	Max	Sum
65BD0	0.14285714	0.13186813	1	2
71CA0	0.07142857	0.07142857	1	1
71CB0	0.28571429	0.37362637	2	4
71ZB0	0.07142857	0.07142857	1	1
71ZC0	0.14285714	0.13186813	1	2
73ET0	0.07142857	0.07142857	1	1
73KD0	0.14285714	0.13186813	1	2
71KM0	0.21428571	0.18131868	1	3
73NA0	2.21428571	4.79670330	8	31
73NB0	0.35714286	0.24725275	1	5
73PA0	1.64285714	1.78571429	4	23
73PB0	1.50000000	0.88461538	4	21
73PD0	2.64285714	4.40109890	7	37
73PPD	0.14285714	0.13186813	1	2
73PP0	0.21428571	0.18131868	1	3
73QA0	0.35714286	0.24725275	1	5
73RB0	1.92857143	1.91758242	5	27
73RE0	3.71428571	2.83516484	7	52
73SB0	0.64285714	0.55494505	2	9
73SD0	0.35714286	0.40109890	2	5
73SF0	0.07142857	0.07142857	1	1
75BAK	0.21428571	0.18131868	1	3

plane) fails, so from five hours on, 80% of the units are surviving. At fifteen hours, two of the units fail at once, so there are 40% of the original units surviving. The fraction surviving drops to 20% at thirty hours, and to 0% at fifty hours, as the last of the five units fails.

If the units were failing according to a Poisson process, with a Poisson failure distribution and an exponential interarrival distribution, then the fraction surviving should follow a curve described by the following equation:

Fraction Surviving$=e^{(-t/\bar{x})}$, where "$\bar{x}$" is the mean time between failures, and "t" is the argument time.

In order to compare the empirical plot of fraction surviving with the theoretical, the mean time to failure of the verified failure intervals was calculated, and this is shown in Table VIII.

The mean times between verified failures which resulted from the data were generally shorter than the worldwide mean times to failure. This is not surprising, since, as discussed above, the mean time between failures which result from the data may be expected to be shorter than the worldwide mean times to failure, since extremely long intervals are not included. However, several of the Work Unit Codes which had a large number of intervals had a mean time between verified failures that was quite close to the worldwide mean. Particularly note the empirical mean time between failures of 73PD0, which is less than 0.102 hrs. or seven minutes off from the worldwide mean time between failures. Especially considering the grouping of failure times caused by sortie length, this is very close agreement. Also surprising are the cases of items 73NA0, 73PB0, and 73RE0, which like 73PD0, have an empirical mean time between verified failures which is greater than the worldwide mean time between failures. There are two probable explanations for this result: first, it may reflect a local variation at Cannon from the worldwide mean, due to such causes as climate, missions, surges, and so on; second, it

TABLE VIII
WORLDWIDE MEAN TIMES BETWEEN FAILURE
AND EMPIRICAL MEAN TIMES BETWEEN VERIFIED FAILURES

Work Unit Code	World MTBF	Empirical MTBVF
51ABE	445.03782	64.66
51ABH	303.49012	67.008[illegible]
51CAC	235.01762	82.5116
61AA0	149.9925	80.5472
61AB0	two items	72.4727
61AC0	two items	90.095[illegible]
61BA0	332.4468	72.1818
65BA0	101.71905	81.3609
73NA0	43.47259	54.7321
73PA0	not available	55.1404
73PB0	43.10159	49.5951
73PD0	42.582183	42.6844
73QA0	156.88735	98.3923
73RB0	68.808917	45.5145
73RE0	28.353511	38.4795
73SB0	175.62346	83.0819
73SD0	207.64119	71.115

may reflect poor maintenance records, which would lead to loss of some true failures due to an inability to verify them according to MAINTLOG's standards.

Figures 2 through 18 show the empirical fraction surviving and the theoretical curve with the empirical mean as parameter. The data were not compared against the worldwide mean; this is an examination of the shape of the fraction surviving curve, rather than an attempted goodness-of-fit test.

3. <u>Test of Exponentiality.</u> To test the exponentiality of the intervals between failures, or rather the exponentiality of time-to-failure, the WE_0 statistic can be calculated and evaluated. (Hahn and Shapiro, 1967:298-299) The WE_0 statistic is calculated by the formula:

$$WE_o = \frac{\sum_{i=1}^{n} (x_i - x)^2}{\left(\sum_{i=1}^{n} x_i\right)^2}$$

The test is two sided in that the observed samples can be rejected as non-exponential if the WE_0 statistics do not fall in the tabled intervals. The test also requires a known value above which all values of x, the inter-arrival times, lie, in this case 0. The tables (Hahn and Shapiro, 1967:334) record values for sample sizes of 7 to 35 so not all WUC's can be tested by this method.

Those six WUC's for which there are more than 35 values can be tested by a chi-squared goodness-of-fit test. The mean of the data for each sample is used to determine the values in flying hours that theoretically divide the data points into ten equal intervals. The actual counts of failures falling between the various boundries are determined and compared with the theoretical. The formula is:

$$X^2 = \frac{k}{n}\left(\sum_{i=1}^{k} M_i^2\right) - n$$

TABLE IX
TEST OF THE EXPONENTIALITY OF INTERFAILURE INTERVALS

WUC	NR	MEAN	STD DEV	S/M	WEo/X^2
51ABE	20	64.66	67.114	1.04	0.057
51ABH	12	67.01	67.44	1.01	0.084
51ABN	10	53.55	78.78	1.47	0.216*
51CAC	17	82.51	71.72	0.87	0.044
61AA0	36	80.54	64.96	0.81	0.018
61AB0	22	72.47	53.32	0.74	0.025
61AC0	21	90.10	67.95	0.75	0.027
61BA0	11	72.18	69.01	0.96	0.083
65AA0	9	90.47	57.28	0.63	0.044
65BA0	23	81.36	61.04	0.75	0.024
73NA0	134	54.73	56.40	1.03	X^2=13.16
73PA0	94	55.14	54.48	0.99	X^2= 9.40
73PB0	122	49.60	56.27	1.13	X^2=22.75*
73PD0	167	42.68	41.16	0.96	X^2=10.78
73QA0	13	98.39	84.91	0.86	0.057
73RB0	117	45.51	46.85	1.03	X^2=10.44
73RE0	219	38.48	41.43	1.08	X^2= 7.44
73SB0	27	83.08	66.03	0.79	0.023
73SD0	20	71.11	75.93	1.07	0.057

* significant at $P < .05$ for X^2 with 8 degrees of freedom, the critical value is 15.5 for P = .005

where k is the number of intervals, always 10 here; n is the number of failures and M_i is the count in each interval. The degrees of freedom are k-2, or 8. Table IX records the results.

Only two WUC's, 51ABN and 73PBO, of the 19 tested are significantly different from the exponential. The hypothesis of exponentiality may be rejected at the 95% confidence level for these two. The graph of fraction surviving for 73PBO, Figure 12, is much like Proschan's description of airborne air conditioner failures (Proschan:1963). The plot of actual failures is uniformly below the theoretical and until it crosses at about 58 flying hours and then is uniformly above it, at least until tail of the distribution about 200 flying hours. The implication is that 73PBO is negative binomially distributed.

C. ANALYSIS OF FAILURE COUNT

1. Introduction. Three procedures were carried out with the count of failures. All three involved manipulation of the mean and variance of the number of failures in two hundred hours. The first procedure was the calculation of the variance-to-mean ratio, which is characteristically 1 for the Poisson distribution, and greater than 1 for the negative binomial. The second procedure was a chi square test for equal means. The third procedure was an estimation of the parameters of a negative binomial distribution to fit the data, if applicable.

2. Variance-to-mean ratio. The variance-to-mean ratio may be used to characterize the Poisson, the binomial, and the negative binomial distributions. The variance-to-mean ratio is by definition equal to 1 for the Poisson distribution. The variance equals the mean, and that single parameter is the parameter of the Poisson distribution. The variance-to-mean ratio for the binomial distribution is characteristically less than one, and the variance-to-mean ratio of the negative binomial distribution is greater than

one. The mean and the variance of the count of failures in two hundred hours was calculated, and their ratio taken.

3. χ^2 Test for Equal Means of Poisson Planes. Although, as mentioned above, the variance-to-mean ratio is characteristic of the Poisson and negative binomial distributions, some random fluctuations must be expected. When does the ratio become statistically significant?

The following test for equal means of n Poisson samples uses the variance-to-mean ratio in a χ^2 test:

$$(n-1)s^2/\bar{x} \sim \chi^2(n-1)$$

In this case, n equals the number of planes, each plane being a data point. The number of planes with at least two hundred flying hours was forty-six, so the critical value of the test would be for $\chi^2(45)$. The number of planes with at least three hundred hours was 14, so the critical value would be $\chi^2(13)$.

4. Estimation of Negative Binomial Parameters. Bain and Wright (1981) developed procedures for estimating the parameters of a negative binomial distribution from the interarrival times. The negative binomial distribution of failures is considered to be a compound Poisson process, in which individual planes have a Poisson failure distribution, and the means for each plane follow the gamma distribution. The parameters of the negative binomial distribution, γ and κ, and the average intensity (the average of the means of the planes) can be calculated as follows:

$$\gamma = \frac{B-A^2}{A} \qquad \kappa = \frac{A^2}{B-A^2} \quad ,$$

where

$$A = \sum_{i=1}^{n} (r_i-1)/n\ T_{r_i}$$

$$B = \sum_{i=1}^{n} (r_i-1)(r_i-2)/n\ T_{r_i}^{\ 2} \quad .$$

T_r is the cumulative time to the rth failure (in this case, time = 0 for each plane starts with the first failure, so T_r would be the r + 1 st failure). n is the number of planes. The average intensity, $E(\nu)$, is $\kappa \times \gamma$. A negative κ or γ is meaningless because of the derivation; a refinement of the estimation to prevent negative parameters was presented by Bain and Wright, but was not implemented in this study. However, the expected value $E(\nu)$ is A, which may be readily calculated as above. A is analogous to the Poisson expected number of failures. For this analysis, those planes which had any failure intervals at all were included in the count of data points, n, but as can be seen from the formula for A, those planes which had only one failure interval do not contribute to A. As B is given above, only those planes with at least three failure intervals contribute to B. Therefore, the anlaysis is only valid for data where at least three failures are determined. It must be noted that this estimation is predicated on the existance of a negative binomial. If the failures are not negatively binomically distributed, the estimations are, of course, invalid. Bain and Wright stated that, in the discrete or count case, κ and γ can be estimated by the following equations:

$$\ell \times \gamma = (s^2/\bar{x}) - 1 \ ; \ \kappa = \bar{x}^2/(s^2 - \bar{x})$$

This calculation can only be performed when $s^2/\bar{x}$ is greater than 1. γ and κ can again be used to provide $E(\nu)$, and, as Bain and Wright showed, even if γ and κ are different, their product $E(\nu)$ may be very close. This is because, as κ gets large, the gamma distribution approaches the normal.

D. DISCUSSION OF RESULTS OF ANALYSIS OF INTERFAILURE TIMES

1. Plots of Empirical and Theoretical Fraction Surviving. The empirical and theoretical fraction surviving were plotted for the seventeen Work Unit Codes with more than ten interfailure points. It cannot be overemphasized

that, with as few as eleven data points, the plot is suggestive, but hardly definitive.

a. 51ABE. Figure 2 shows the empirical and theoretical fraction surviving for 51ABE. The data points are clustered below the theoretical curve up to about 80 flying hours, and then are above the curve to about 155 flying hours, and then below it again. This suggests that there may not be a single mean for the 14 planes which had failure intervals for 51ABE. Note, however, that the data mean was 64.66 flying hours, while the worldwide mean was 445 hours.

b. 51ABH. All but one point of Figure 3 is below the theoretical curve. This indicates that the failure intervals may not have been exponential. It is important to keep in mind that these data, covering only 12 failure intervals and 7 planes, are extremely sparse, and the sample mean of 67 hours is only one fifth the worldwide mean of 303.

c. 51CAC. Again on Figure 4, a series of runs may be noted; with the caveat that these data are extremely sparse, they do not seem to represent an exponential interarrival distribution. Note that the derived mean is only about one quarter the size of the worldwide mean.

d. 61AAO. These data (in Figure 5) seem to cluster above and then below the theoretical line. They cover 36 intervals on 28 planes. These points were ordered, that is, arranged in ascending order, so some runs are to be expected, but they are some indication that the means may not be equal.

e. 61ABO. Figure 6 gives the empirical and theoretical fraction surviving for 61ABO. 61ABO was listed twice in the D029 product list, with two different demand rates for the two different items. Since both items are found on all planes, no conclusions can be drawn.

f. 61ACO. Figure 7 shows 61ACO. This Work Unit Code also stands for two items.

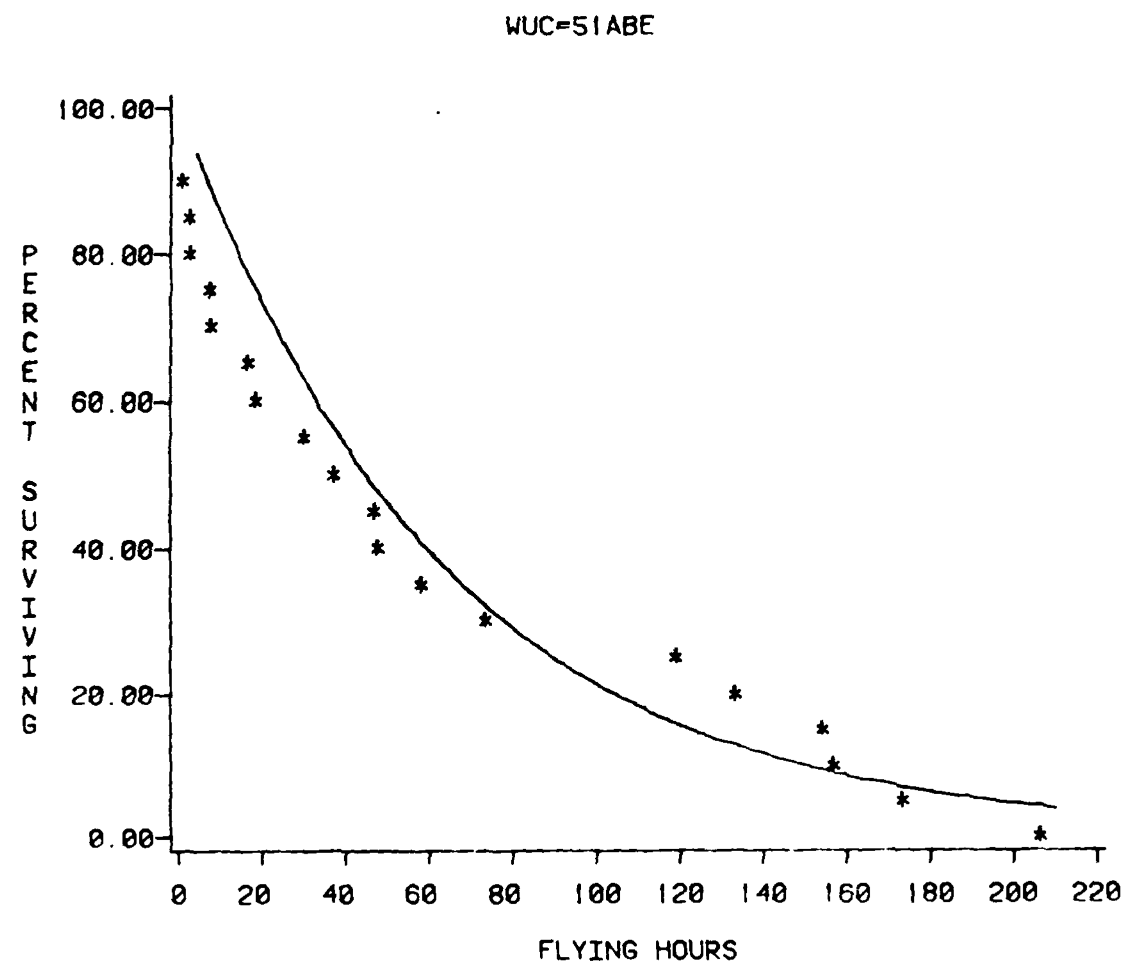

Figure 2. Empirical and Theoretical Fraction Surviving for 51ABE

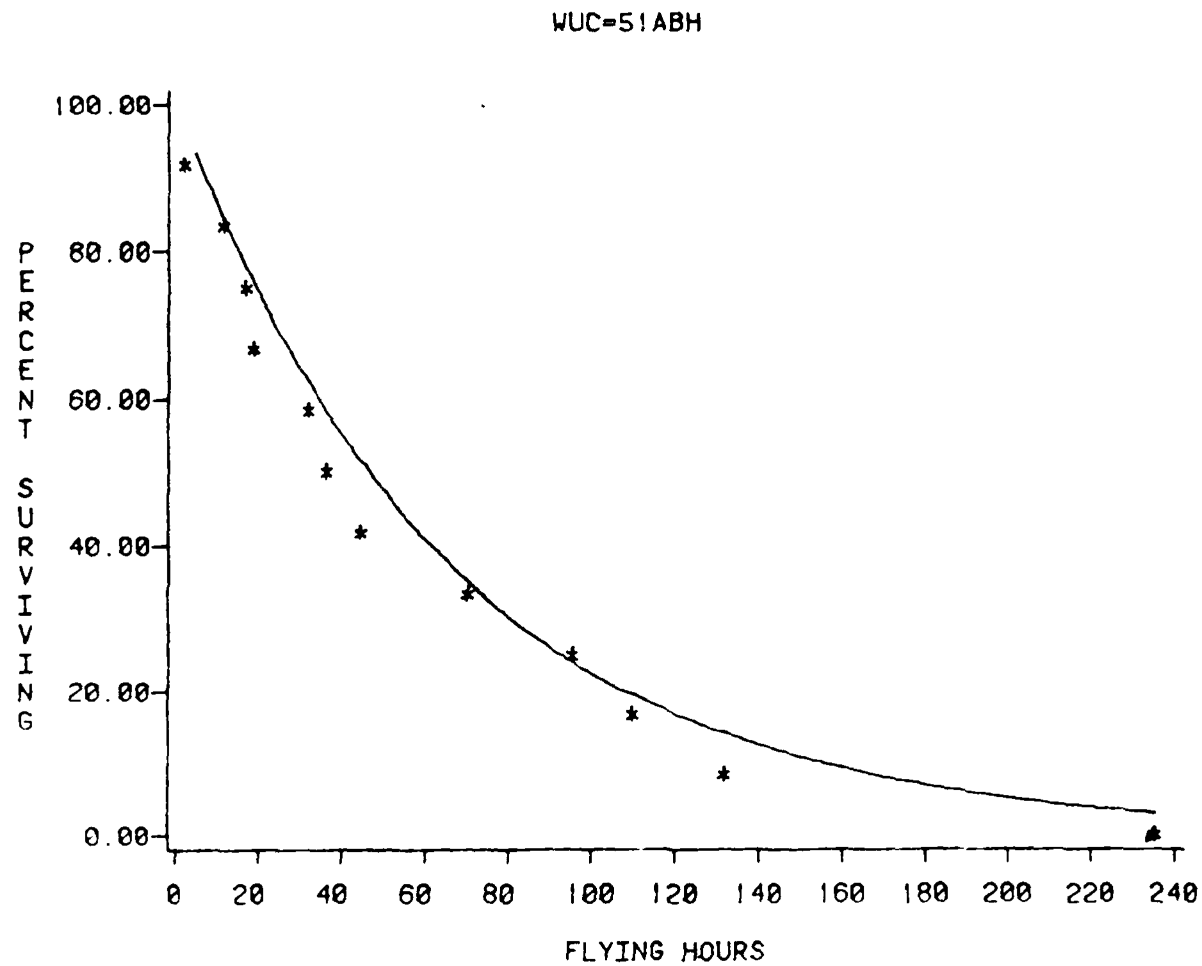

Figure 3. Empirical and Theoretical Fraction Surviving for 51ABH

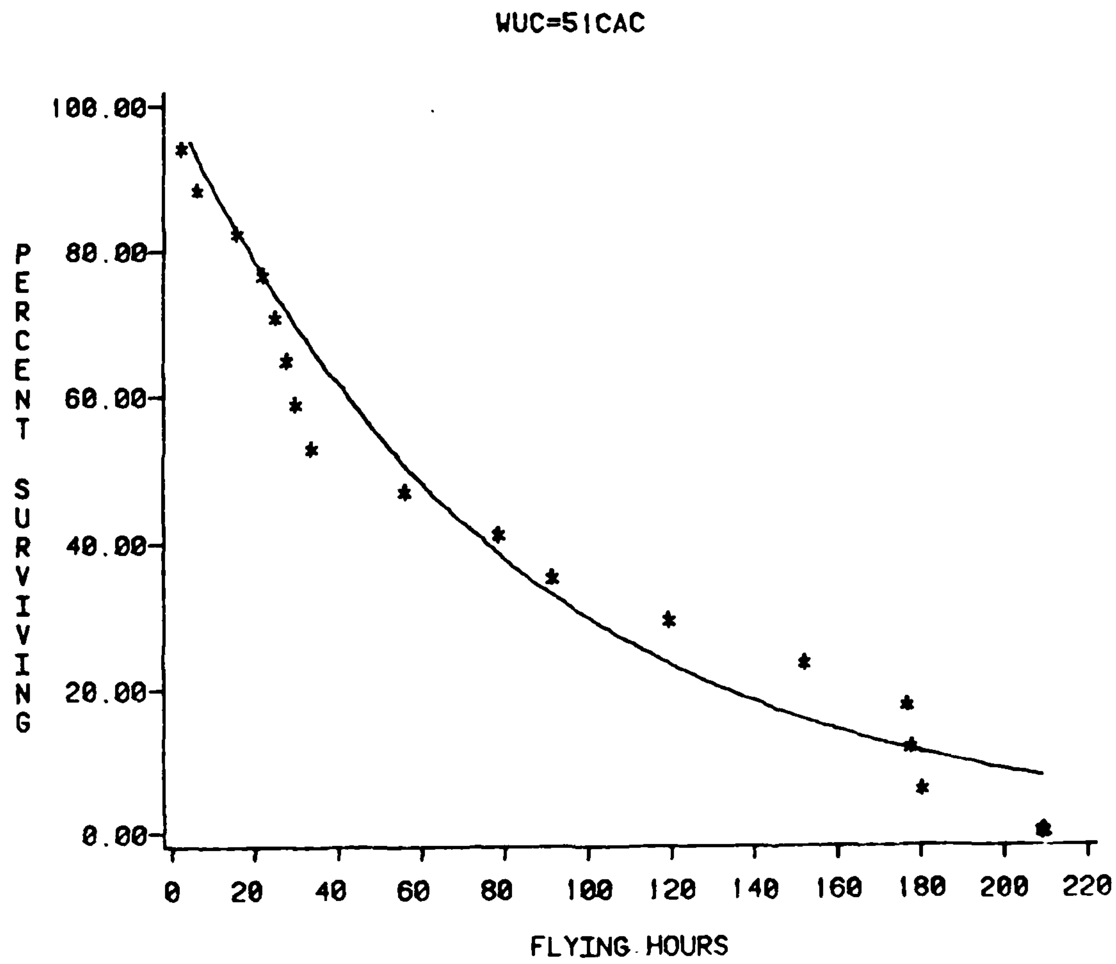

Figure 4. Empirical and Theoretical Fraction Surviving for 51CAC

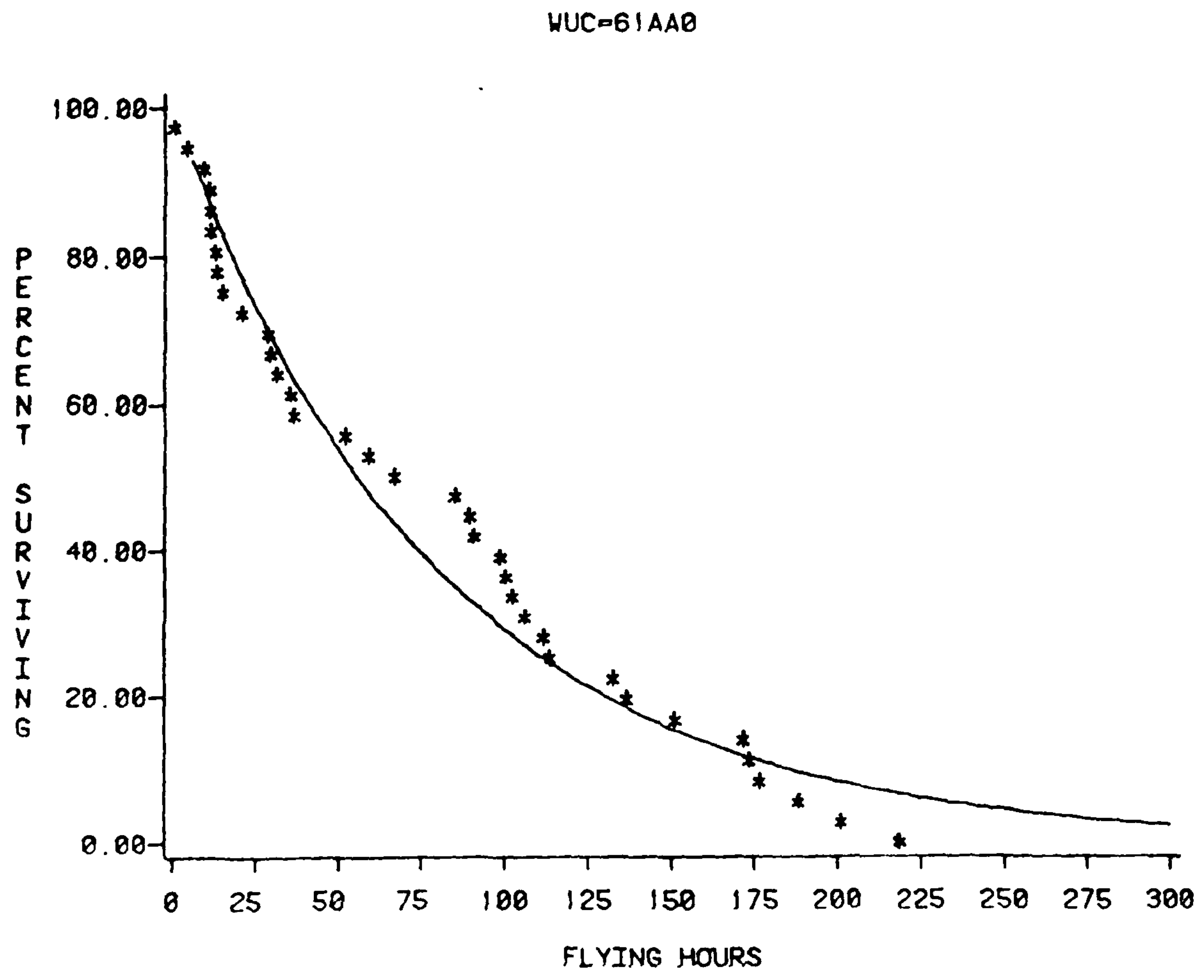

Figure 5. Empirical and Theoretical Fraction Surviving for 61AA0

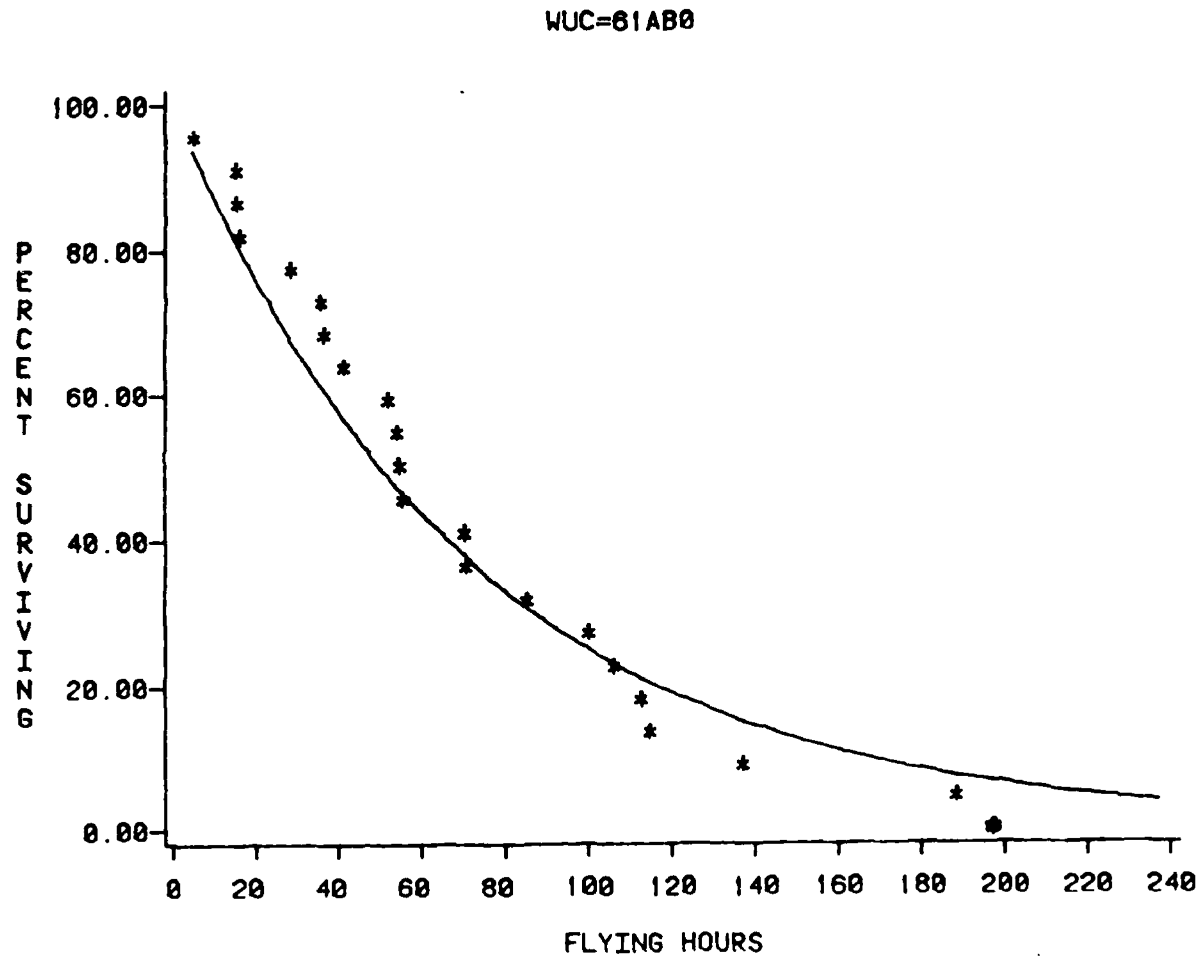

Figure 6. Empirical and Theoretical Fraction Surviving for 61AB0

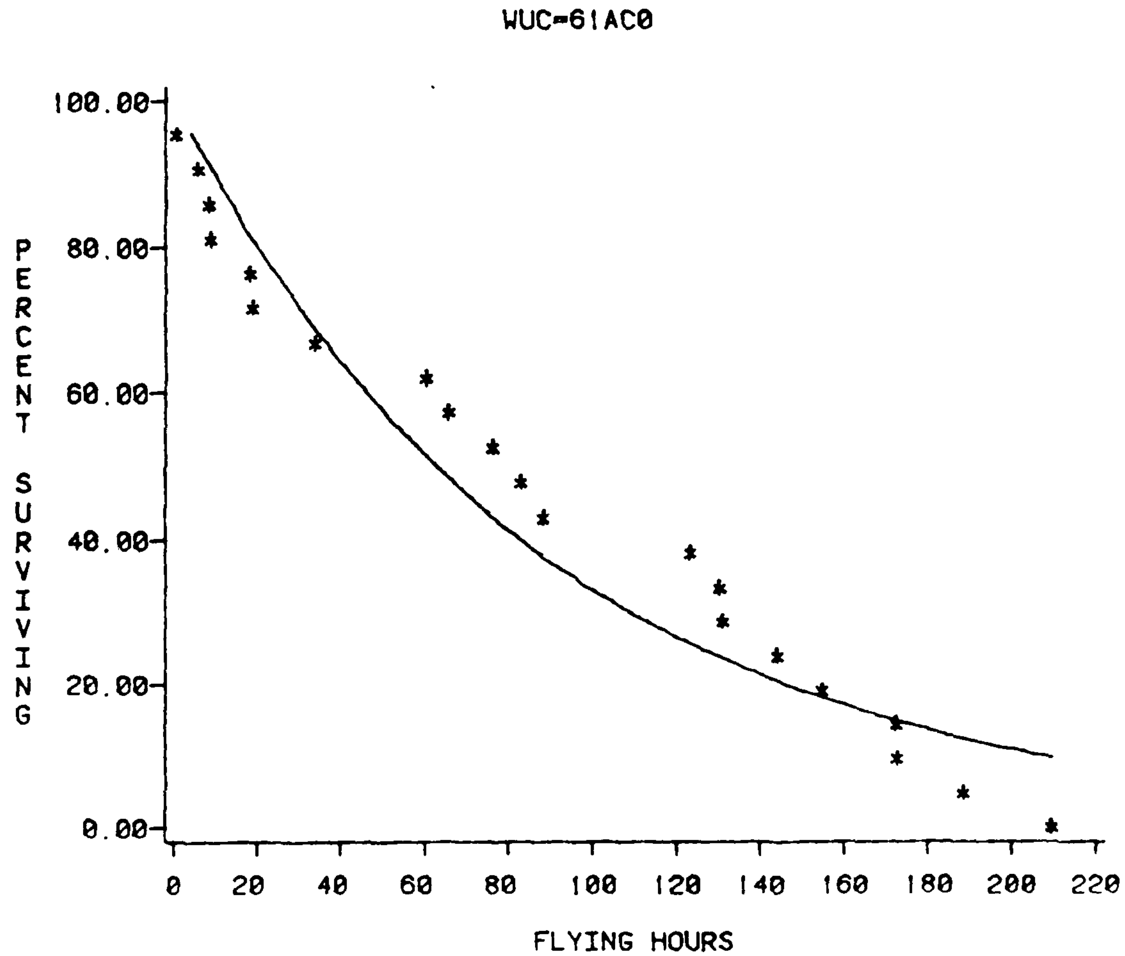

Figure 7. Empirical and Theoretical Fraction Surviving for 61AC0

g. <u>61BAO</u>. With 11 data points, it is not safe to draw very strong conclusions about this WUC. The derived mean is only about one quarter the length of the worldwide mean. Figure 8 shows most points are below the theoretical line.

h. <u>65BAO</u>. Figure 9 shows the points, representing 23 intervals on 18 planes, clustering, first above and then below the line, indicating there may not be a single mean on all 18 planes.

i. <u>73NAO</u>. Figure 10 is extremely interesting. This large number of points, covering 134 intervals on 58 planes, clearly is below the theoretical curve up to about 60 hours, then above it until the theoretical and empirical trends meet at the tail of the curve. This seems to indicate a possible negative binomial distribution.

j. <u>73PAO</u>. Like Figure 10, Figure 11 shows very dense data, representing 94 failures on 49 planes. Extended runs above and below the theoretical line may be marked here also. 73PAO is apparently not a WRSK item, since it was not listed in the D029 Product List.

k. <u>73PBO</u>. Very strong trends on a large amount of data may be noted in Figure 12. The derived mean is quite close to the worldwide mean.

l. <u>73PDO</u>. The derived mean time between failures of 73PDO is within minutes of the worldwide mean, and Figure 13 would seem to indicate that 73PDO follows a Poisson process, except for the bulges at 50 and 100 hours.

m. <u>73QAO</u>. The sparse data of 73QAO, in Figure 14, have a derived mean time between failures of about half the length of the worldwide mean.

n. <u>73RBO</u>. Figure 15 shows 73RBO clustering strongly above and then below the line, crossing only once. It seems unlikely that 73RBO follows a Poisson process.

o. <u>73REO</u>. Figure 16 shows the theoretical and empirical fraction surviving for 73REO. Although there is a strong trend below and then above

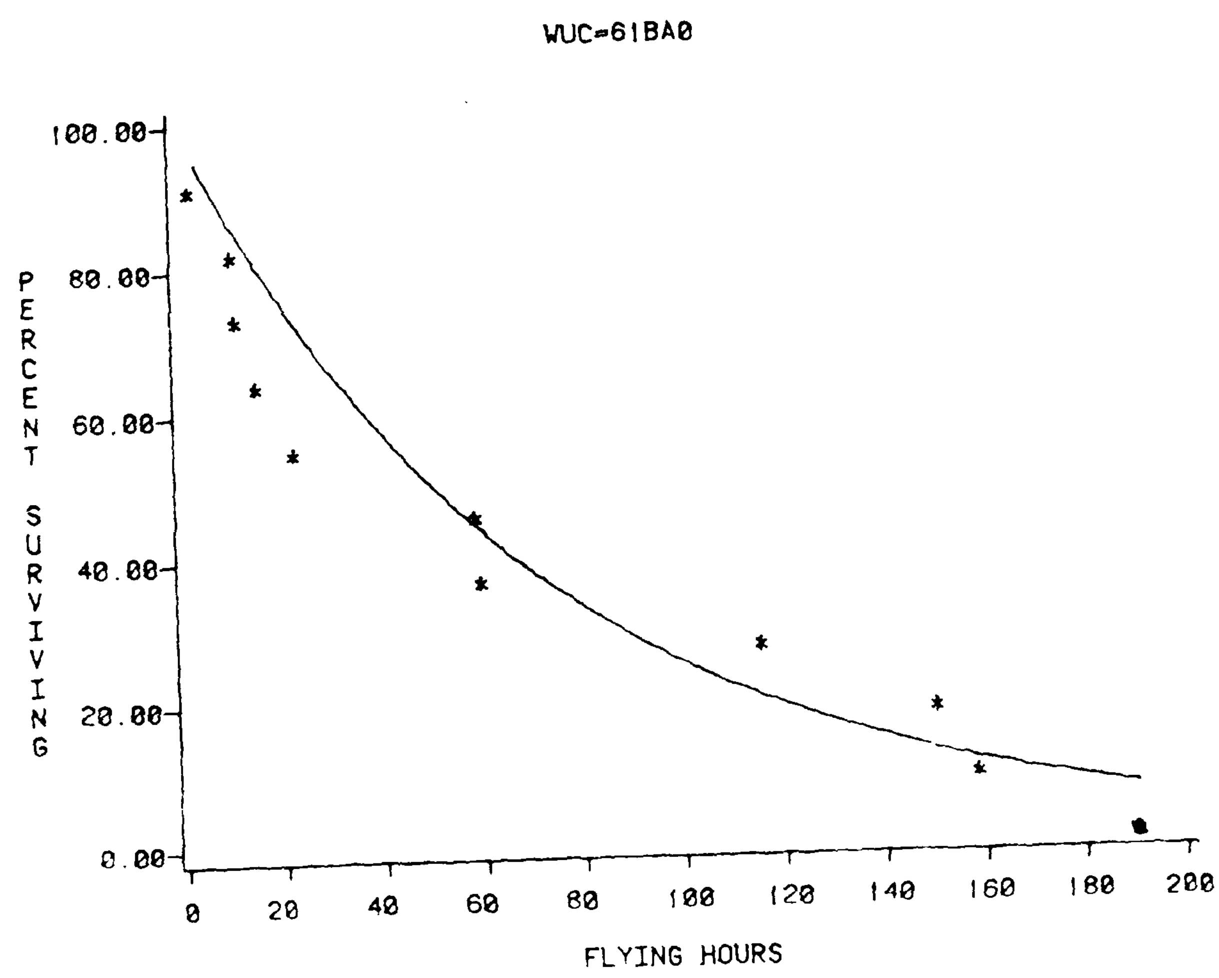

Figure 8. Empirical and Theoretical Fraction Surviving for 61BA0

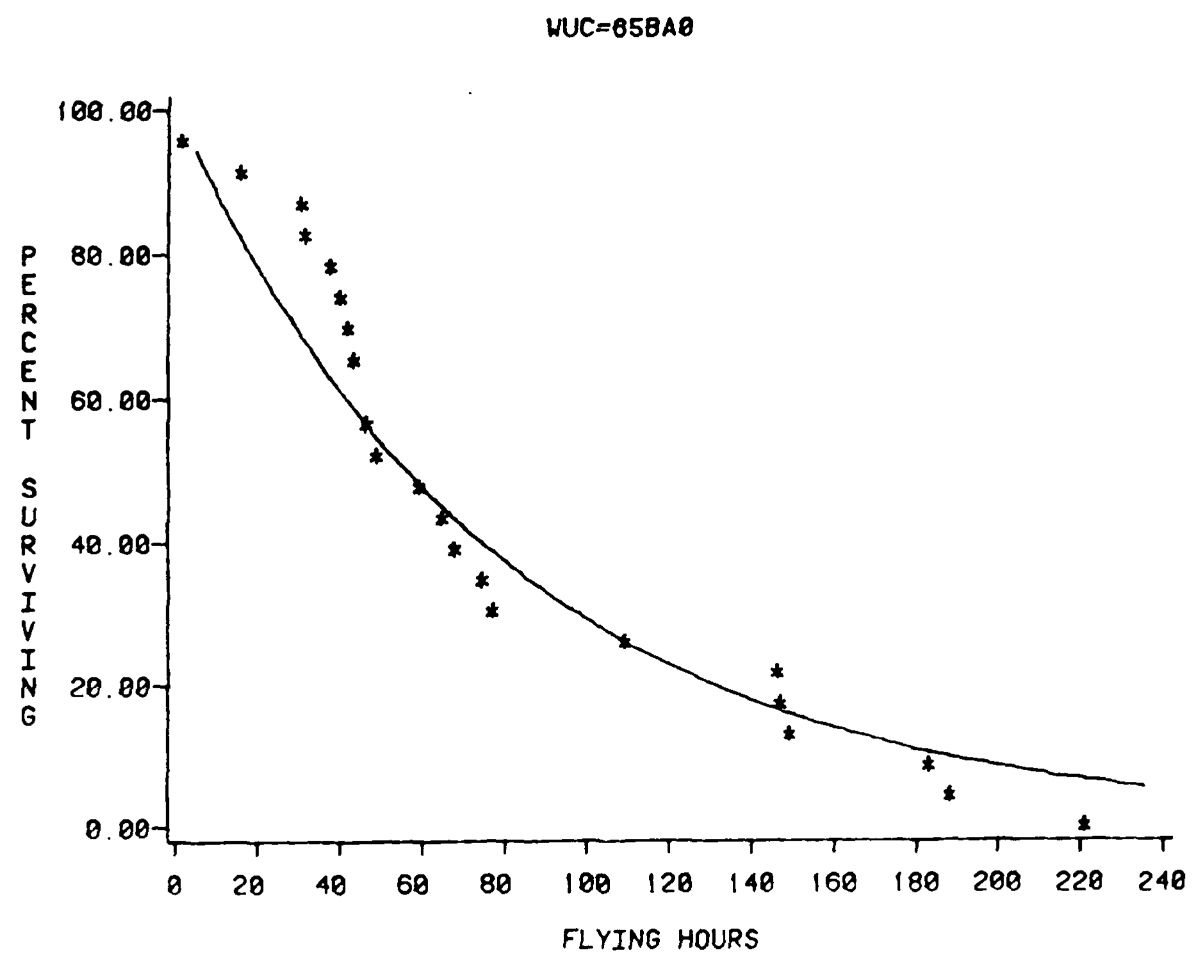

Figure 9. Empirical and Theoretical Fraction Surviving for 65BA0

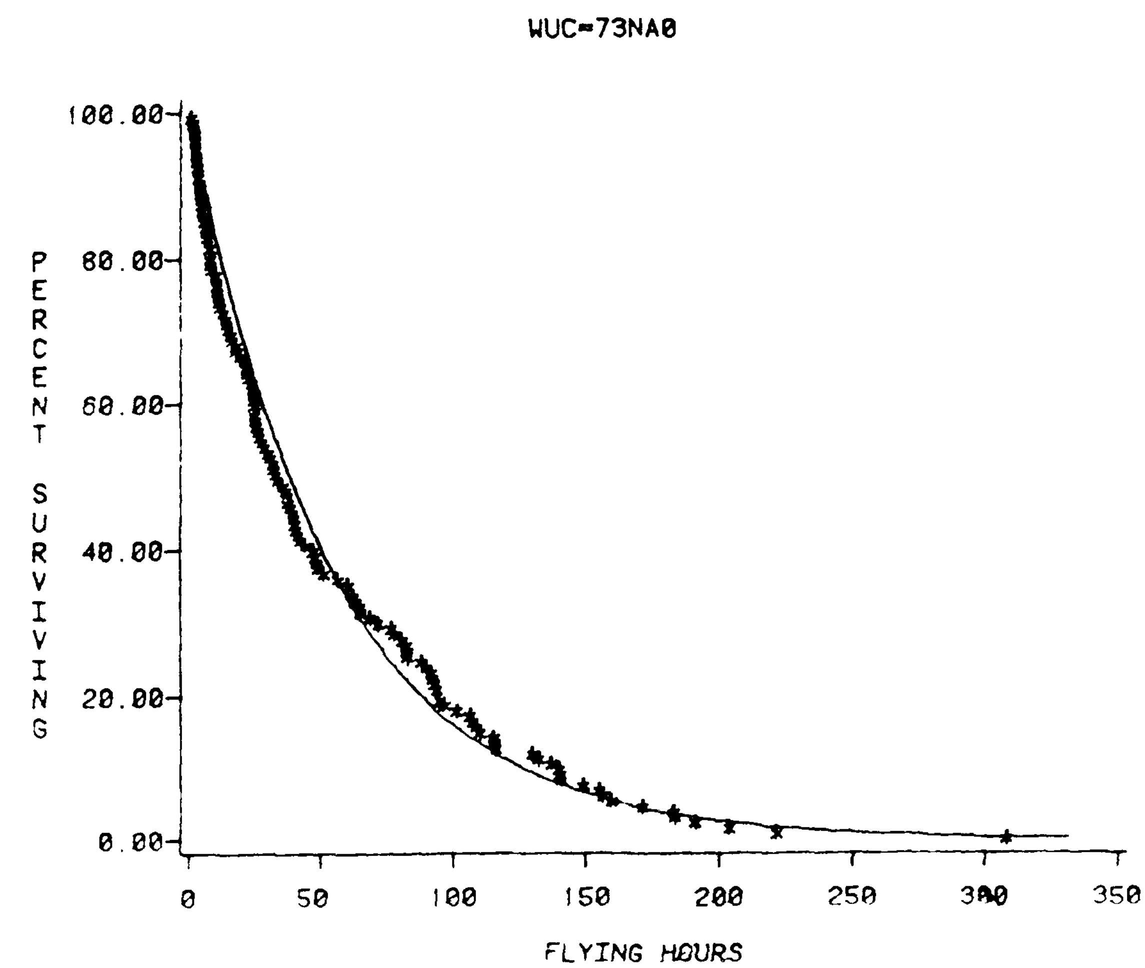

Figure 10. Empirical and Theoretical Fraction Surviving for 73NA0

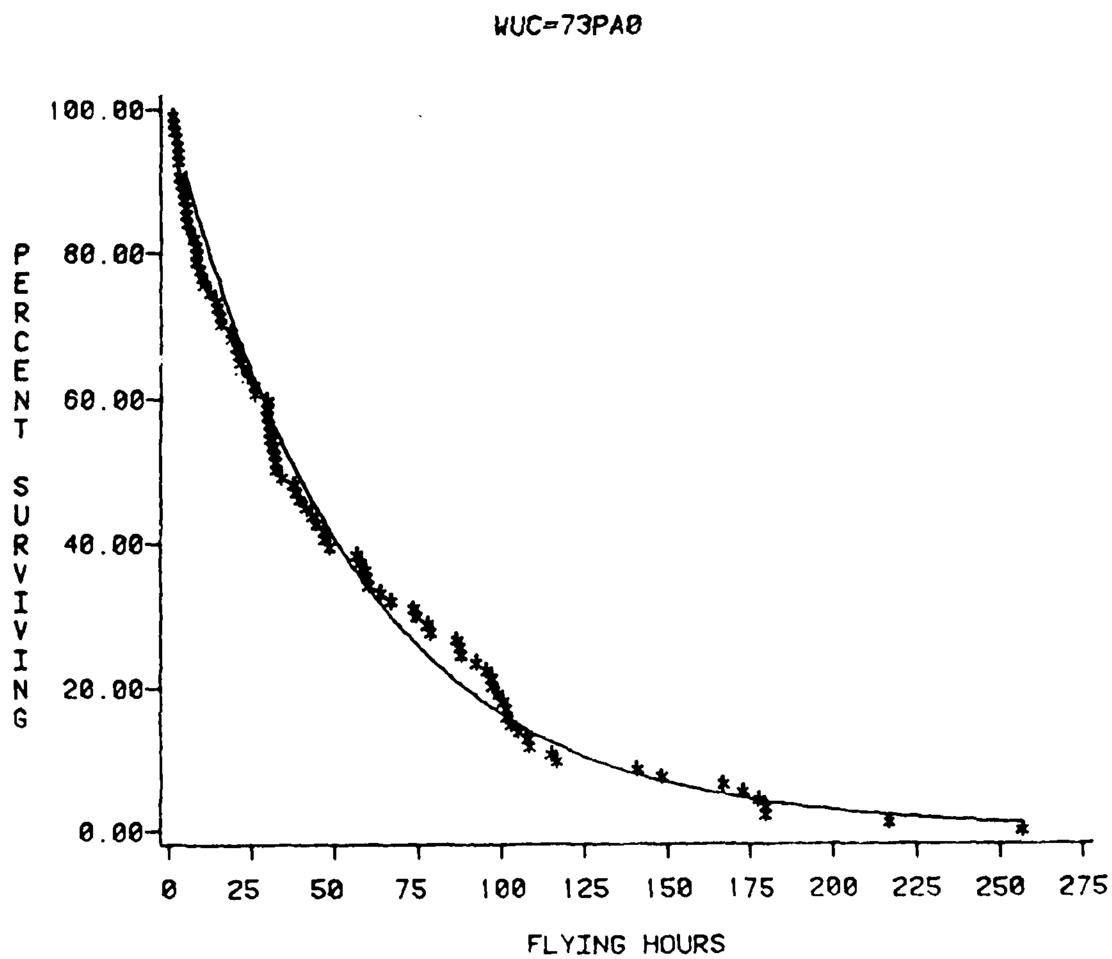

Figure 11. Empirical and Theoretical Fraction Surviving for 73PA0

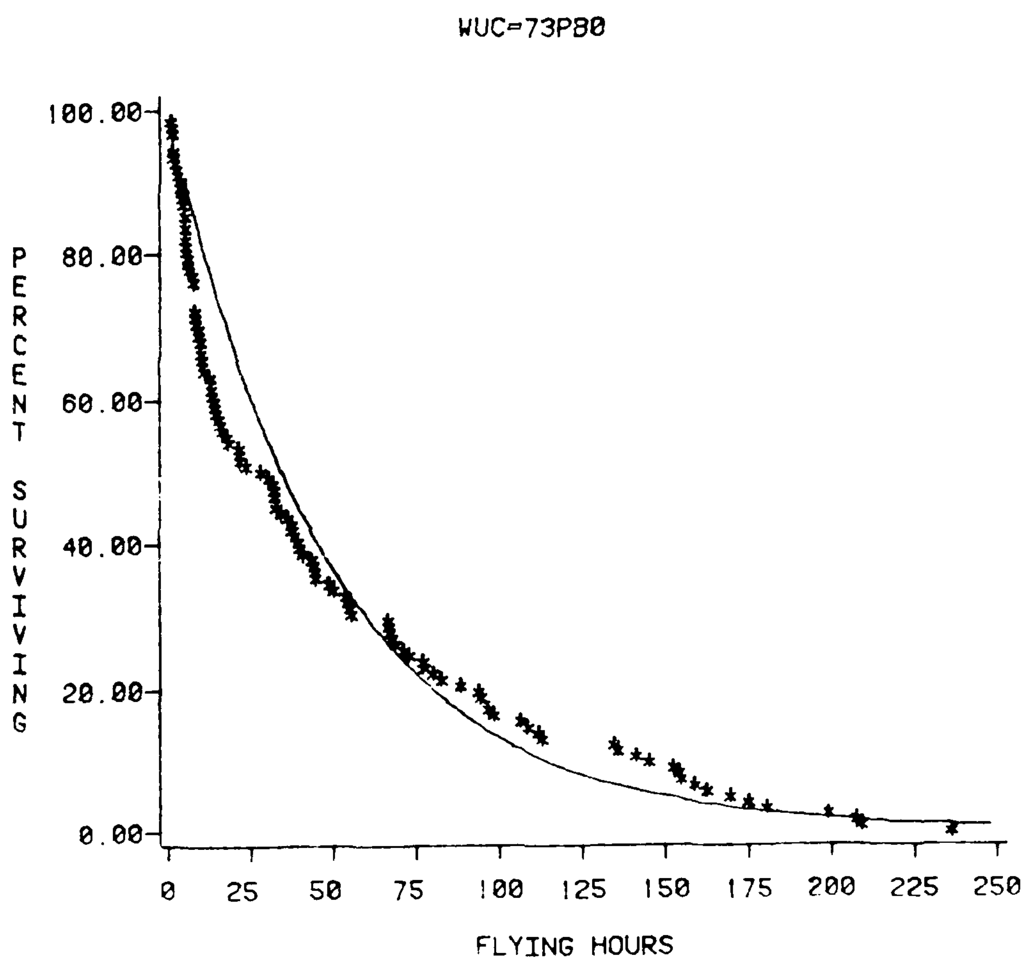

Figure 12. Empirical and Theoretical Fraction Surviving for 73P80

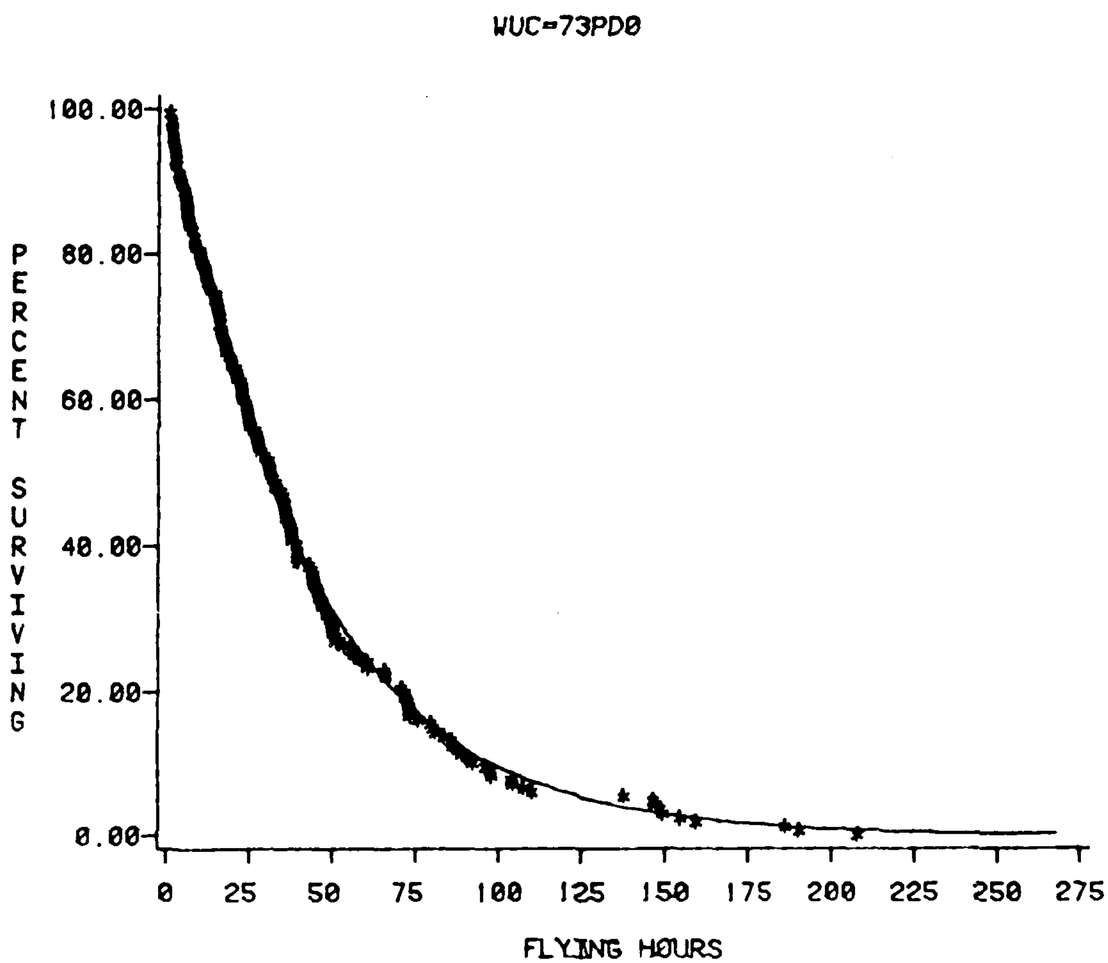

Figure 13. Empirical and Theoretical Fraction Surviving for 73PD0

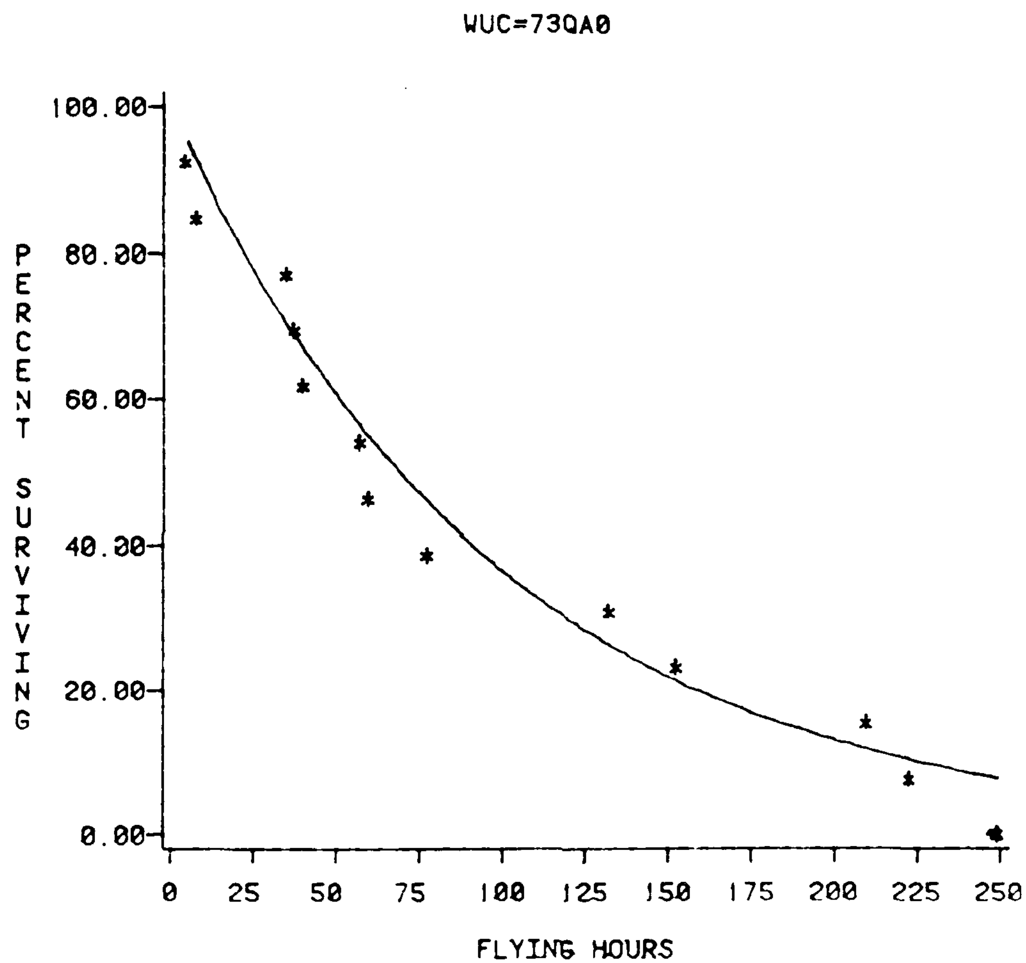

Figure 14. Empirical and Theoretical Fraction Surviving for 73QA0

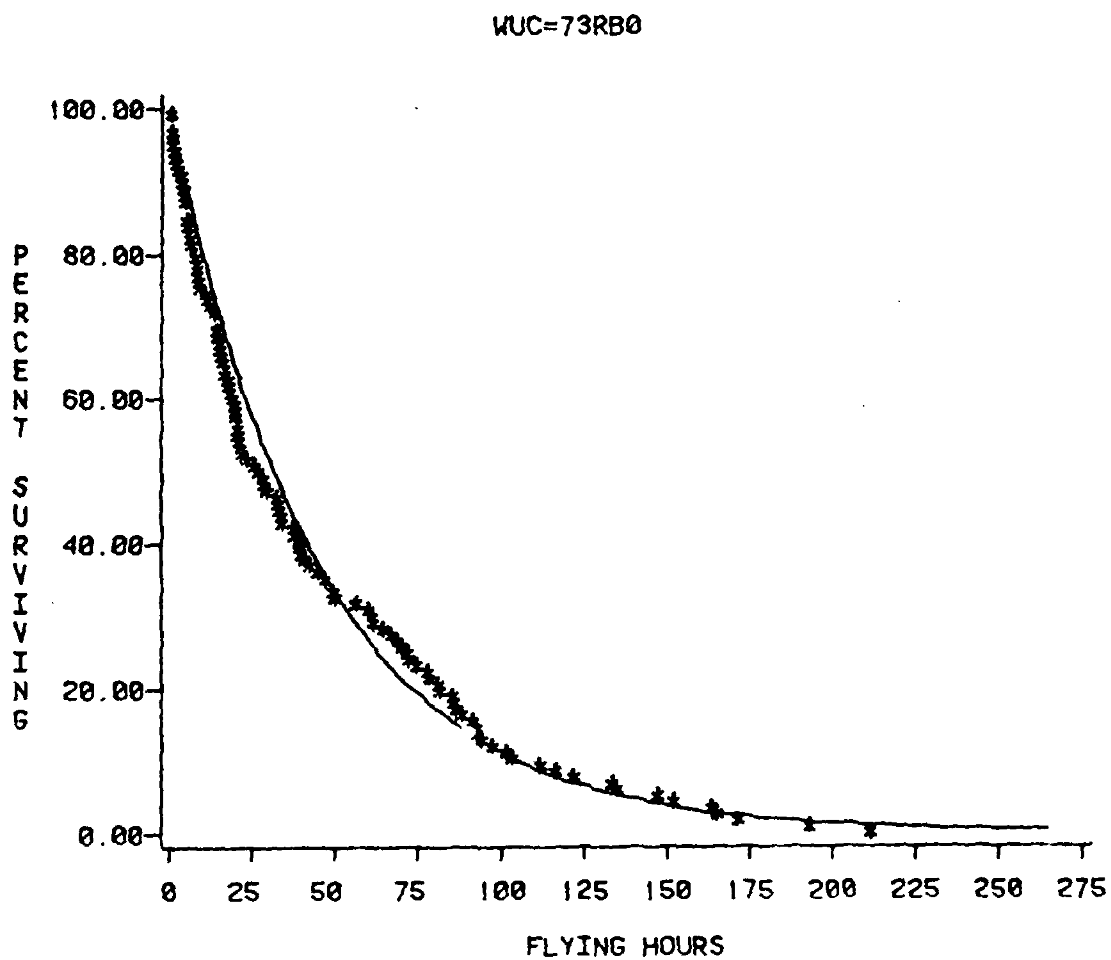

Figure 15. Empirical and Theoretical Fraction Surviving for 73RB0

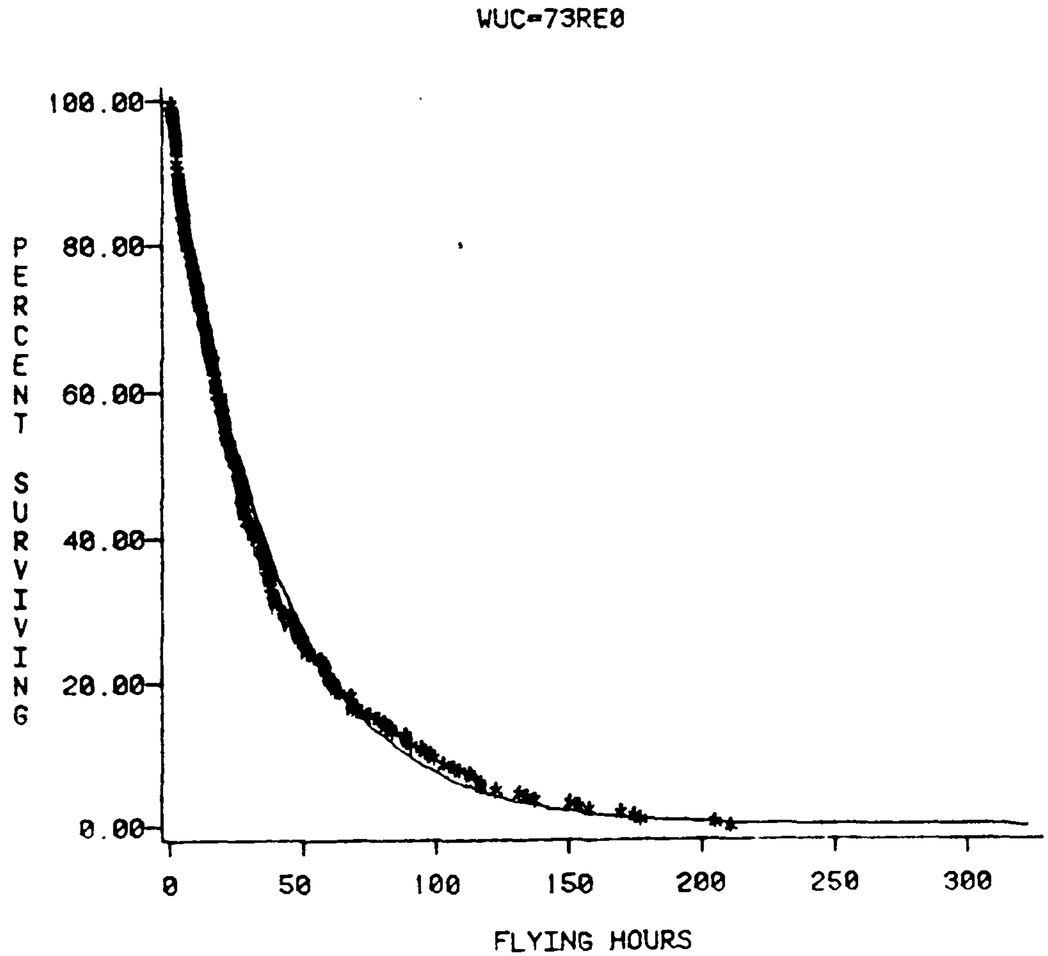

Figure 16. Empirical and Theoretical Fraction Surviving for 73RE0

the line, it cannot be said from the figure whether it is statistically significant.

p. 73SB0. This figure (17) shows strong clusters above and below the line.

q. 73SD0. Figure 18 shows a large deviation from the theoretical curve. The derived mean is about a third the worldwide mean.

2. Estimation of Negative Binomial Parameters. Parameters for the negative binomial distribution were estimated for those Work Unit Codes for which graphs were prepared. The same warnings regarding the sparseness of the data must be kept in mind, as were emphasized in the discussion of the plots. These parameters are of interest when compared with the results of the estimation of parameters from the discrete data.

E. DISCUSSION OF RESULTS OF ANALYSIS OF FAILURE COUNT

1. Variance-to-mean ratio. Tables X and XI give the variance-to-mean ratio for the failure counts of planes with 200 and 300 flying hours, respectively. The tables also indicate the range of values and the sum of the failures obtained. In every case except 73RE0 at 300 hours, there was at least one plane which flew the whole period with no failure on the WUC in question.

Although the variance-to-mean ratio is suggestive, the results illustrate the need for caution. Table XII shows the results at 200 flying hours and 300 flying hours for those WUCs which had failures in both cases. The table also gives the total number of failures in each case. In some cases, apparently, most of the failures were concentrated on those planes that flew fewer than 300 hours.

There is substantial agreement on some WUCs; for example, 73NA0 shows a ratio of 1.5 at 200 hours, and of 2.2 at 300 hours; 73PD0 shows a ratio of 1.8

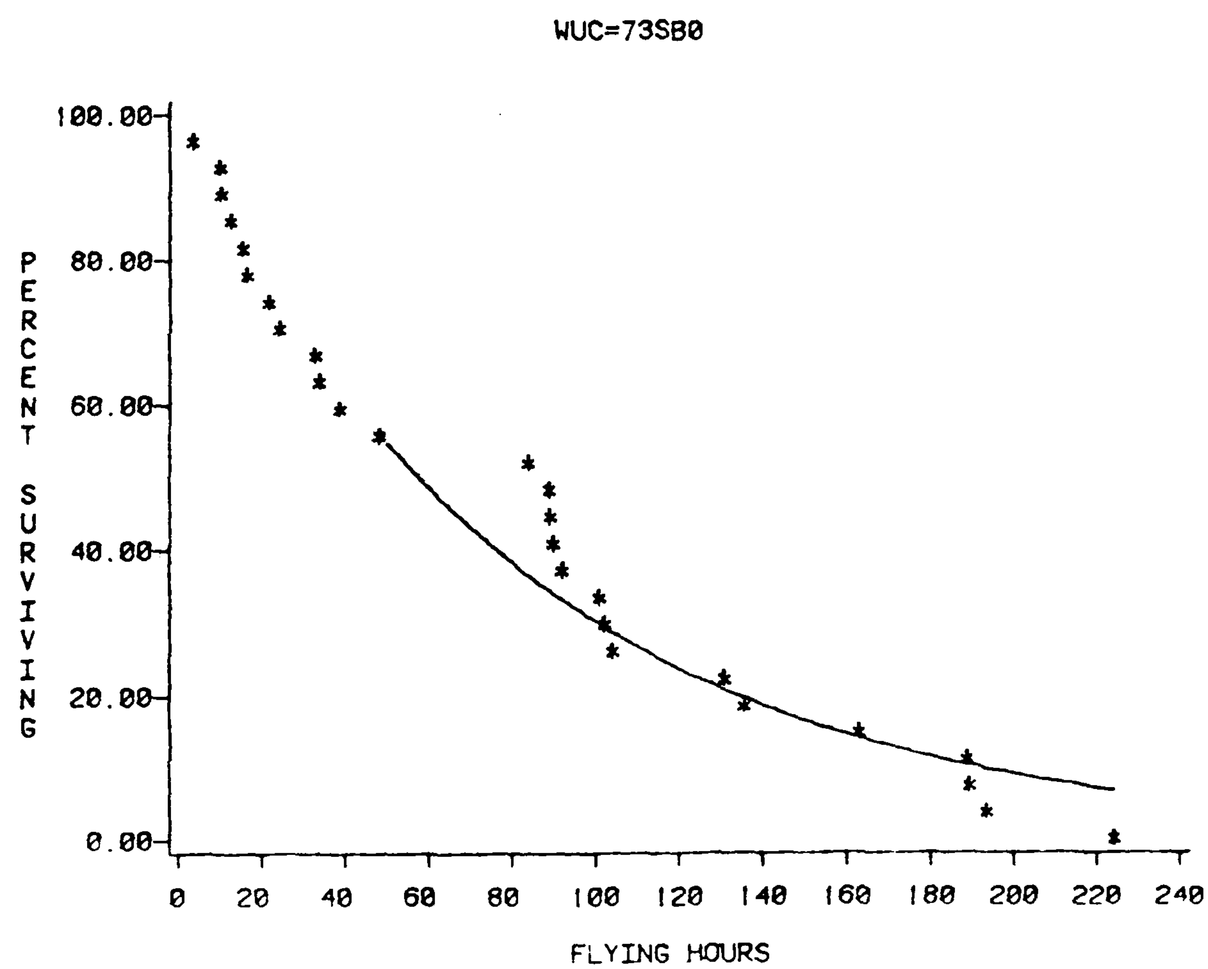

Figure 17. Empirical and Theoretical Fraction Surviving for 73SB0

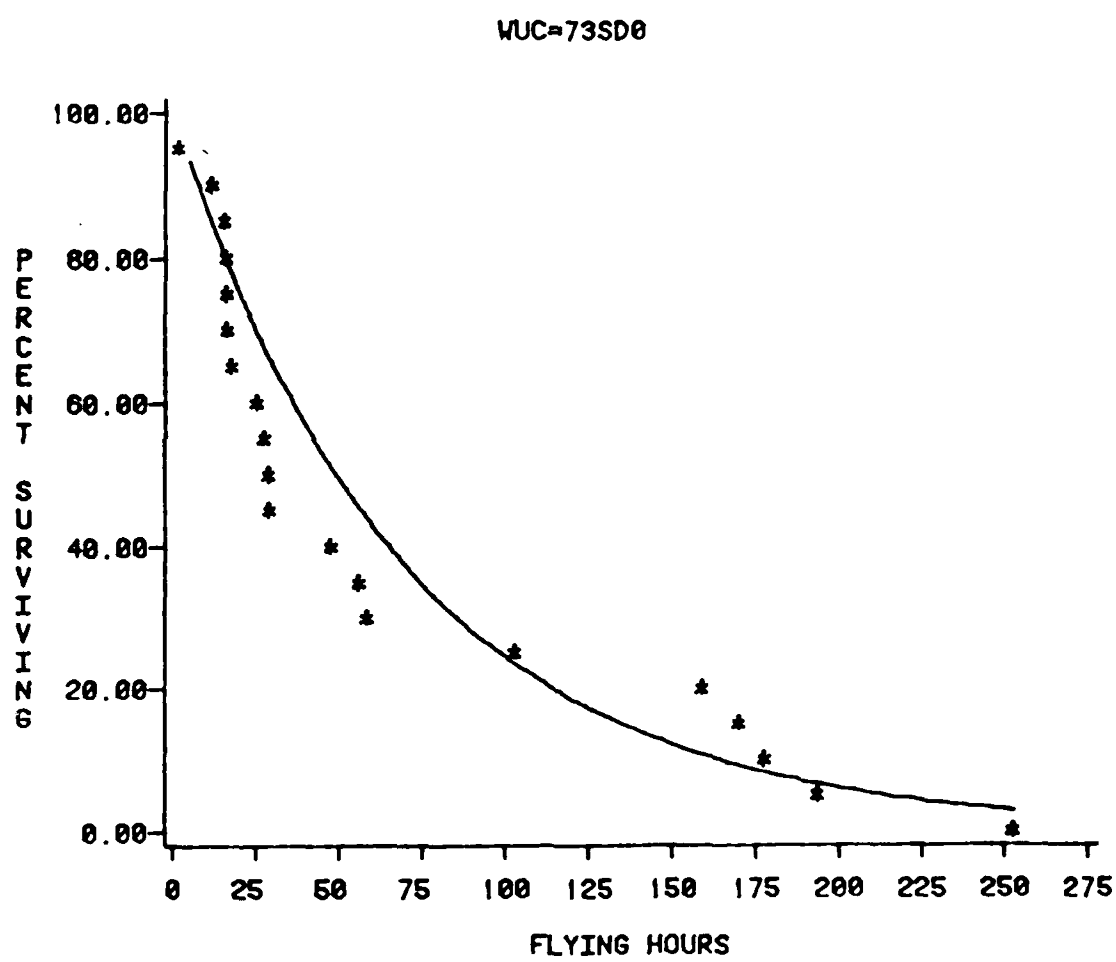

Figure 18. Empirical and Theoretical Fraction Surviving for 73SD0

TABLE X
VARIANCE-TO-MEAN RATIO OF FAILURES AT 200 FLYING HOURS

WUC	Var/Mean	Max	Sum	WUC	Var/Mean	Max	Sum
13AAA	0.9555555	1	3	51ABN	1.2952380	1	4
13BCA	0.9777778	1	2	51ABQ	1.0000000	1	1
13BCB	0.9777778	1	2	51CAA	0.9333333	1	4
13BCC	1.0000000	1	1	51CAC	0.7076023	2	1[illegible]
13CDA	1.4444444	2	4	61AA0	1.1247311	4	31
13ECA	0.9333333	1	4	61AB0	1.2026666	3	25
13HCB	0.9777778	1	2	61AC0	0.9050505	2	22
14BCA	0.9555555	1	3	61BA0	0.9614814	2	15
14BCD	0.9333333	1	4	61BB0	0.9777778	1	2
14BCE	0.9777778	1	2	61BC0	1.1587301	2	7
16CAC	1.3200000	2	5	65AA0	0.7777778	1	11
44AAH	0.9555555	1	3	65BA0	0.7589743	2	16
44AAJ	0.9555555	1	3	65BC0	1.0044444	2	10
46DAA	1.0000000	1	1	65BD0	0.9111119	1	5
49BAA	1.0000000	1	1	71CA0	2.1851852	3	9
51ABA	0.9111111	1	5	71CB0	1.1000000	2	8
51ABD	0.9777778	1	2	71D00	1.0000000	1	1
51ABE	1.4977777	3	20	71ZA0	0.9555555	1	3
51ABH	1.4370370	3	12	71ZB0	0.9555555	1	3
51ABL	0.9333333	1	4	71ZC0	0.8666666	1	7

TABLE X (Continued)

WUC	Var/Mean	Max	Sum	WUC	Var/Mean	Max	Sum
71ZD0	1.0000000	1	1	73PPD	0.9555555	1	3
73ET0	0.9777778	1	2	73PP0	0.9259258	2	12
73KD0	0.9333333	1	4	73QA0	0.9636363	2	11
73KM0	1.1587301	2	7	73RB0	1.6216524	9	78
73NA0	1.5292929	7	88	73RE0	1.2105555	9	160
73NB0	0.9259258	2	12	73SB0	1.3662222	4	25
73PA0	0.8615384	4	78	73SD0	0.7944444	2	16
73PB0	1.2783626	6	95	73SF0	0.9111111	1	5
73PD0	1.7931034	10	116	75BAK	0.8666666	1	7

TABLE XI
VARIANCE-TO-MEAN RATIO OF FAILURES AT 300 FLYING HOURS

WUC	Var/Mean	Max	Sum	WUC	Var/Mean	Max	Sum
13BCB	1.0000000	1	1	71CA0	1.0000000	1	1
13ECA	1.0000000	1	1	71CB0	1.3076922	2	4
14BCA	1.0000000	1	1	71ZB0	1.0000000	1	1
14BCD	1.0000000	1	1	71ZC0	0.9230769	1	2
16CAC	1.0000000	1	1	73ET0	1.0000000	1	1
44AAH	0.9230769	1	2	73KD0	0.9230769	1	2
44AAJ	1.0000000	1	1	73KM0	0.8461538	1	3
49BAA	0.9230769	1	2	73NA0	2.1662531	8	31
51ABE	1.0000000	1	1	73NB0	0.6923076	1	5
51ABH	1.1538461	2	7	73PA0	1.0869565	4	23
51ABN	1.3076919	2	4	73PB0	0.5897435	4	21
51ABQ	0.9230769	1	2	73PD0	1.6652806	7	37
51CAC	1.0000000	2	8	73PPD	0.9230769	1	2
61AA0	0.6223776	2	11	73PP0	0.8461538	1	3
61AB0	1.5999999	3	10	73QA0	0.6923076	1	5
61AC0	1.1538461	2	7	73RB0	0.9943020	5	27
61BA0	0.7692307	1	4	73RE0	0.7633136	7	52
61BC0	2.0000000	2	2	73SB0	0.8632478	2	9
65AA0	0.8461538	1	3	73SD0	1.1230769	2	5
65BA0	1.4102564	3	12	73SF0	1.0000000	1	1
65BC0	0.9230769	1	2	75BAK	0.8461538	1	3
65BD0	0.9230769	1	2				

TABLE XII
COMPARISON OF VARIANCE-TO-MEAN RATIOS AT 200 AND 300 HOURS

	200 Hours		300 Hours	
WUC	Var/mean	Sum	Var/mean	Sum
13BCB	0.9777778	2	1.0000000	1
14BCA	0.9555555	3	1.0000000	1
14BCD	0.9333333	4	1.0000000	1
16CAC	1.3200000	5	1.0000000	1
44AAH	0.9555555	3	0.9230769	2
44AAJ	0.9555555	3	1.0000000	1
49BAA	1.0000000	1	0.9230769	2
51ABE	1.4977777	20	1.0000000	1
51ABh	1.437037	12	1.1538461	7
51ABN	1.295238	14	1.3076919	4
51ABQ	1.0000000	1	0.9230769	2
51CAC	0.7076023	19	1.0000000	8
61AA0	1.1247311	31	0.6223776	11
61ABQ	1.2026666	25	1.5999999	10
61AC0	0.9050505	22	1.1538461	7
61BA0	0.9614814	15	0.7692307	4
61BC0	1.1587301	7	2.0000000	2
65AA0	0.7777778	11	0.8461538	3
65BA0	0.7589743	16	1.4102564	12
65BC0	1.0044444	10	0.9230769	2
65BD0	0.9111119	5	0.9230769	2

TABLE XII (Continued)

WUC	200 Hours Var/mean	Sum	300 Hours Var/mean	Sum
71CA0	2.1851852	9	1.0000000	1
71CB0	1.1000000	8	1.3076922	4
71ZB0	0.9555555	3	1.0000000	1
71ZC0	0.8666666	7	0.9230769	2
73ET0	0.9777778	2	1.0000000	1
73KD0	0.9333333	4	0.9230769	2
73KM0	1.1587301	7	0.8461538	3
73NA0	1.5292929	88	2.1662531	31
73NB0	0.9259258	12	0.6923076	5
73PA0	0.8615384	78	1.0869565	23
73PB0	1.2783626	95	0.5897435	21
73PD0	1.7931034	116	1.6652806	37
73PPD	0.9555555	3	0.9230769	2
73PP0	0.9259258	12	0.8461538	3
73QA0	0.9636363	11	0.6923076	5
73RB0	1.6216524	78	0.994302	27
73RE0	1.2105555	160	0.7633136	52
73SB0	1.3662222	25	0.8632478	9
73SD0	0.7944444	16	1.1230769	5
73SF0	0.9111111	5	1.0000000	1
75BAK	0.8666666	7	0.8461538	3

at 200 hours and 1.7 at 300 hours. In some cases there is not as much agreement. The results of the next test indicated whether the variance-to-mean ratio was statistically significant.

2. χ^2 Test for Equal Means of Poisson Planes. The χ^2 test described in the analysis section was performed on the variance-to-mean ratios. The sparseness of the data dictates caution in interpreting the results of the chi-square test. Hald (1952: 727) cites Sukhatme (1938) in noting that, if the value of the estimated mean (which would be the mean number of failures in this case) is as small as between 1 and 5, the chi-square approximation is still good even if there are only a few data points (in this case, between 5 and 15 airplanes); if the estimated mean is even smaller, (about 1) there should be more data points (more than 15 airplanes). There were 46 planes with 200 flying hours, and 14 planes with 300 flying hours. The chi-square values were calculated for all cases where the mean was at least 0.5.

Table XIII gives the mean, variance-to-mean ratio, and the chi-square value for each case, and tells whether the hypothesis of equal means may be rejected, and if so, at what confidence level. Note that in some cases, the hypothesis of equal means for a WUC cannot be rejected for one data set, but can be rejected for the other. The Poisson distribution may be rejected for 61AB0 with .90 confidence for those planes with 300 flying hours, but not for the planes with 200 flying hours. This may be due to the fact that, as previously mentioned, 61AB0 represents two different items of supply. Of more interest is the rejection of the Poisson at 200 flying hours for 73PB0 and 73RB0, but the failure to reject the Poisson for these WUCs at 300 flying hours. This indicates that these WUC's display more homogeneous behavior on the planes at 300 hours than on the planes at 200 hours. One possible source of this distinction is the proportion of planes that had undergone surge in each group. All eighteen planes that participated in the surge Coronet Hammer

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TABLE XIII
CHI SQUARE TEST OF VARIANCE-TO-MEAN RATIO

WUC	Mean	200 Hours $s^2/\bar{x}$	$45(s^2/\bar{x})$	Poisson?
61AA0	0.67391304	1.1247311	50.612899	
61AB0	0.54347826	1.20266666	54.119997	
65BA0	0.56521739	0.7589743	34.153843	
73NA0	1.91304348	1.5292929	68.818181	reject at .975
73PA0	1.68565217	0.8615384	38.769228	
73PB0	2.06521739	1.2783626	57.526317	reject at .90
73PD0	2.52173913	1.7931034	80.689653	reject at .995
73RB0	1.69565217	1.6216524	72.974358	reject at .99
73RE0	3.47826087	1.2105555	54.474997	

WUC	Mean	300 Hours $s^2/\bar{x}$	$13(s^2/\bar{x})$	Poisson?
51ABH	0.50000000	1.1538461	15.001299	
51CAC	0.57142857	1.0000000	13.000000	
61AA0	0.78571429	0.6223776	8.0909088	
61AB0	0.71428561	1.5999999	20.799998	reject at .90
61AC0	0.50000000	1.1538461	14.999999	
65BA0	0.85714286	1.4102564	18.333333	
73NA0	2.21428571	2.1662531	28.161290	reject at .99
73PA0	1.64285714	1.0869565	14.130434	

TABLE XIII (Cor'inued)

WUC	Mean	300 Hours $s^2/\bar{x}$	$45(s^2/\bar{x})$	Poisson?
73PBO	1.50000000	0.5897435	7.6666655	
73PDO	2.64285714	1.6652806	21.648647	reject at .90
73RBO	1.92857143	0.9943020	12.925926	
73REO	3.71428571	0.7633136	9.9230768	

Chi Square Percentiles

	.90	.95	.975	.99	.995
13	19.8	22.4	24.7	27.7	29.8
45	57.5	61.7	65.4	70.0	73.2

(Source: Hahn and Shapiro, 1967: 314, 315)

flew at least 200 hours in the total period covered by this study. The proportion of Coronet Hammer planes rose to 9 out of 14 in the group that had flown at least 300 hours, an increase from 40% (18/46) to 64% (9/14).

Table XIV summarizes the different conditions under which the home station and deployed Coronet Hammer planes were operated during the surge. The surge lasted from 6 May to 9 June 1980.

It can be seen that it was not the length of sorties flown that changed for the surged aircraft, bu+ rather the frequency of the sorties.

Finally, note that it is not possible to reject the Poisson distribution for 51ABH, 51CAC, 61AAO, 61ACO, 65BAO, 73PAO, or 73REO from either set of data, and that it is possible to reject the Poisson for 73NAO and 73PDO from both sets of data.

3. Estimation of Negative Binomial Parameters. The negative binomial parameters γ and κ, as well as the average intensity $E(\nu)$ were calculated from the mean and the variance. Table XV gives the results obtained from the data obtained at 200 and at 300 hours.

F. CONCLUSION OF ANALYSIS

As a result of each method of analysis used on the data, an estimate of the average intensity of failure has been obtained. The various estimates are compiled in Table XVI. In some cases the estimates diverge widely from each other and from the worldwide total demand rate. It must be assumed that an adequate sample of true failures was not obtained in these cases. However, in other cases such as 73REO and 73PDO, no more than a factor of 3 divides the smallest estimate from the largest, or from the worldwide total demand rate. A discrepancy of this order of magnitude may reflect differences between operating conditions at Cannon and at other locations, and may also reflect some loss of data due to poor recordskeeping. In these cases, at least, a representative sample of failures may be assumed to have been obtained.

TABLE XIV
SUMMARY DATA FOR CORONET HAMMER

	Home Station	Deployed
Number of Planes	47.1 (on the average)	18
Sortie Rate (avg.) (sorties per day per plane)	0.38	1.5
Sortie Length (avg.)	2.353	2.338
Total Hours Flown	971.8	1,347.1

TABLE XV
ESTIMATE OF NEGATIVE BINOMIAL PARAMETERS FROM FAILURE DATA

200 Flying Hours

WUC	γ	κ	$E(\nu)$
13CDA	0.00222222	0.1956522	0.000434782
16CAC	0.00160000	0.3396736	0.000543478
51ABE	0.00248889	0.8734472	0.002173913
51ABH	0.00218519	0.5969044	0.001304348
51ABN	0.00147619	1.030855	0.001521739
61BCO	0.00079365	0.958695	0.000760869
65BCO	0.00002222	48.917272	0.001086957
71CAO	0.00592593	0.1650813	0.000978261
71CBO	0.00050000	1.73913	0.000869565
73KMO	0.00079365	0.958695	0.000760869
73NAO	0.00264646	3.6143375	0.009565217
73PBO	0.00139181	7.4191617	0.010326086
73PDO	0.00396552	3.179584	0.012608695
73RBO	0.00310826	1.7748475	0.008478261
73REO	0.00105278	16.519443	0.017391304
73SBO	0.00183111	1.484012	0.002717391

TABLE XV (Continued)

300 Flying Hours

WUC	γ	κ	E(ν)
51ABH	0.0051282	1.413044	0.001666667
51ABN	0.00102564	0.9285707	0.000952381
65BA0	0.00136752	2.0892851	0.002857143
71CB0	0.00102564	0.9285707	0.000952381
73NA0	0.00388751	1.8986321	0.007380952
73PA0	0.00028986	18.892861	0.005476190
73PD0	0.00221760	3.9725444	0.008809524
73SD0	0.00041026	2.9017811	0.001190476

TABLE XVI
ESTIMATES OF AVERAGE INTENSITY

WUC	Worldwide Total Demand Rate	$\frac{1}{MTBVF}$	A	200 E(ν)	300 E(ν)
13CDA	0.000566	--	--	0.0004348	--
16CAC	0.001210	--	--	0.0005435	--
51ABE	0.002247	0.0154655	0.00000323939	0.0021739	--
51ABH	0.003295	0.0149235	0.00650613	0.0013043	0.0016667
51ABN	0.003333	--	--	0.0015217	0.0009524
51CAC	0.004255	0.0121194	0.00735294	--	--
61AA0	0.006667	0.012415	0.00301424	--	--
61BA0	0.003008	0.0138539	0.000725163	--	--
61BC0	0.000860	--	--	0.007609	--
65BA0	0.009831	0.0122909	0.00148495	--	0.0028571
65BC0	0.009011	--	--	0.0010870	--
71CA0	0.000611	--	--	0.009783	--
71CB0	0.000758	--	--	0.008696	0.0009524
73KM0	0.001459	--	--	0.0007609	--
73NA0	0.023003	0.0182708	0.00332362	0.0095652	0.0073810
73PA0	--	0.0181355	0.00532502	--	0.0054762
73PB0	0.023201	0.0201632	0.0135108	0.0103261	--
73PD0	0.023484	0.0234277	0.0147474	0.0126087	0.0088095
73QA0	0.006374	0.0101633	0.00177683	--	--

TABLE XVI (Continued)

WUC	Worldwide Total Demand Rate	$\frac{1}{MTBVF}$	A	200 E(ν)	300 E(ν)
73RBO	0.014533	0.021971	0.0112246	0.0084783	--
73REO	0.035269	0.0259878	0.0198407	0.0173913	--
73SBO	0.005694	0.0120363	0.00440269	0.0027174	--
73SDO	0.004816	0.0140617	0.00281795	--	0.0011905

Of particular interest is the difference between the estimates of failure intensity from the failure data for airplanes with 200 flying hours and those with 300 flying hours. This suggests that estimates of deployment requirements for spares from peacetime needs may not always be accurate.

IV. ANALYSIS OF THE EFFECT OF SURGE

A. INTRODUCTION

The primary purpose of the WRSK is to support aircraft which are to be deployed under wartime conditions. If the failure distribution is significantly different under these conditions than under normal useage, then the WRSK will not be properly configured if the number and types of WUC's included are based on normal useage. The assumption that wartime failure distributions are the same as the distributions of normal useage induced failures needs to be addressed.

The 27th Tactical Fighter Wing did not engage in any conflicts during the period for which data was recorded. The Wing did, however, take part in an extended deployment exercise, Coronet Hammer.

It is possible to isolate the effect of Coronet Hammer on the distribution of malfunctions, and draw some conclusions. How valid these are for the case of wartime deployment depends upon the similarity between mission profiles.

To test the effect of Coronet Hammer, all malfunctions on items installed before but not failing before the exercise and all malfunctions on WUC's installed during the exercise were removed with their intervals or times to failure. This includes items installed before and removed during or after surge, those WUC's installed during surge and removed during or after surge. This reduced the data from 1146 failure intervals to 971 failure intervals. The 175 intervals removed were on WUC's that had experienced the surge conditions of Coronet Hammer.

The 175 intervals are spread among too many different WUC's and airplanes to be handled as a set. In addition, the differences in amount of surge conditions and normal conditions of useage will vary widely. Therefore the set of WUC's which failed without the effects of Coronet Hammer is analyzed to

determine whether there are differences to the total set.

There are two analysis conducted. The first analysis is concerned with the interval data on mean time to verified failure. The second analysis is concerned with the discrete data which describes the distribution of differences in failure rates among aircraft.

B. ANALYSIS OF INTERFAILURE INTERVALS

The interfailure interval data recorded under non-surge conditions were subjected to identical testing as the total set. The results are shown on Table XVII. Unlike the total data set, the results of the analysis of which are shown on Table IX, the hypothesis of exponentiality cannot be rejected at the 95% confidence level for any of the 19 WUC's. The effect of removal of surge-stressed items is to produce a set of data more closely distributed as the exponential. Table XVIII records the values of WE_0 for 95% confidence of acceptance of the hypothesis of exponentiality or the critical value for the chi-squared test of goodness-of-fit for eight degrees of freedom.

In five of six cases where the x^2 goodness-of-fit were calculated, the fit worsened when surge-stressed data are included. In one case 73PB0 the hypothesis of exponentiality of the total set is rejected where it is excepted on the non-surge set. Likewise, 51ABN is rejected as exponential when surge-stressed data are included and exponentiality is accepted when they are not.

Some caution is advisable. In every case, more data are available for the total set than the non-surge set due simply to inclusion of those failures. It is unlikely that increasing the number of failure intervals is solely the reason for the difference in fit because the 19 cases analyzed in the interval test contained anywhere from 8 to 219 intervals and simple increases in number to not affect the goodness-of-fit. There are other conditions that might influence the fit, however, if there was a difference in

TABLE XVII
TEST OF THE EXPONENTIALITY OF INTERFAILURE
INTERVALS OF WUC IN NON-SURGE

WUC	NR	MEAN	STD DEV	S/M	WEo/X2
51ABE	16	55.92	66.15	1.18	0.087
51ABH	11	72.93	67.38	0.92	0.078
51ABN	9	31.07	35.99	1.15	0.149
51CAC	15	80.03	70.21	0.88	0.051
61AA0	34	79.75	66.80	0.84	0.020
61AB0	17	68.02	50.11	0.74	0.032
61AC0	19	79.49	62.01	0.78	0.032
61BA0	9	69.04	69.84	1.01	0.114
65AA0	8	81.39	53.87	0.66	0.055
65BA0	20	65.92	47.46	0.72	0.026
73NA0	106	49.03	45.58	0.93	X^2= 8.34
73PA0	84	50.86	50.14	0.99	X^2= 7.33
73PB0	106	44.97	50.44	1.12	X^2=14.94
73PD0	137	43.82	42.20	0.96	X^2= 4.97
73QA0	10	93.67	80.36	0.86	0.074
73RB0	102	44.38	45.49	1.03	X^2=10.55
73RE0	185	38.65	41.11	1.06	X^2= 4.95
73SB0	23	75.93	61.42	0.81	0.028
73SD0	18	54.24	57.69	1.06	0.063

TABLE XVIII
COMPARISON OF THE TEST STATISTICS FOR THE TOTAL SET
AND NON-SURGE SET OF INTERFAILURE INTERVAL DATA

WUC	TOTAL SET WE_0/X^2	CRITICAL VALUES FOR 95% CONFIDENCE	NON-SURGE SET WE_0/X^2	CRITICAL VALUES FOR 95% CONFIDENCE
51ABE	0.053	0.021-0.090	0.087	0.023-0.113
51ABH	0.084	0.025-0.153	0.078	0.025-0.166
51ABN	0.216	0.085-0.184	0.149	0.025-0.205
51CAC	0.044	0.023-0.107	0.051	0.024-0.119
61AA0	0.018	0.014-0.045	0.020	0.014-0.046
61AB0	0.025	0.020-0.080	0.032	0.023-0.107
61AC0	0.027	0.020-0.085	0.032	0.022-0.096
61BA0	0.083	0.025-0.166	0.114	0.025-0.205
65AA0	0.044	0.025-0.205	0.055	0.025-0.230
65BA0	0.024	0.019-0.075	0.026	0.021-0.090
73NA0	X^2=13.16	15.5	X^2= 8.34	15.5
73PA0	X^2= 9.40	15.5	X^2= 7.33	15.5
73PB0	X^2=22.75	15.5	X^2=14.94	15.5
73PD0	X^2=10.78	15.5	X^2= 4.97	15.5
73QA0	0.057	0.025-0.140	0.074	0.025-0.184
73RB0	X^2=10.44	15.5	X^2=10.55	15.5
73RE0	X^2= 7.44	15.5	X^2= 4.95	15.5
73SB0	0.023	0.017-0.05	0.028	0.019-0.075
73SD0	0.057	0.021-0.090	0.063	0.022-0.101

recordkeeping during Coronet Hammer that tended to either unduly lengthen or shorten the intervals recorded consistantly, the findings would reflect these changes instead of or in addition to actual effects of surge. Such situations as increased inability to verify malfunctions or failure to officially recognize malfunctions in non-mission essential equipment under surge conditions could lead to the worsening fit.

The choice of that set of aircraft for participation which, for whatever reason, fail at lower rates would tend to confuse the analysis. Those aircraft which took part in Coronet Hammer have more recorded flying hours than those which did not. This bases the sample somewhat and the goodness-of-fit could reflect the aircraft selection rather than the effects of surge.

Nonetheless, inclusion of surge-stressed items tends to bias the goodness-of-fit from the exponential and toward the negative binomial as an appropriate model.

C. ANALYSIS OF FAILURE COUNT

The purpose of the analysis of failure count is to determine whether rates of failure of a WUC are Poisson distributed among airplanes. If the rates of failure are Poisson distributed in the fleet and the rate is constant, though different, in each airplane, the resulting combined distribution of the fleet as a whole will be Poisson. The WRSK, which is meant to support a fleet, would reflect a Poisson distribution as well. If the rates of failure among airplanes is gamma distributed rather than Poisson distributed, the model of fleet failures would appropriately be negative binomial.

The effect of surge may be to shift the rate of failure of airplanes, making the distribution of fialure rates non-Poisson. To test this possibility, the distribution of failure rates among airplanes can be tested

for Poisson distribution without the inclusion of failures of stressed by surge. If there is a tendancy toward the Poisson, it would indicate that failure rates are shifted by surge.

In the description of count failure for the entire fleet and all data, only five item distributions were rejected in the chi-square test for a Poisson distribution of failures among airplanes. These WUC's were 73NA0 and 73PD0 at both 200 and 300 hours, 73PB0, and 73RB0 at 200 hours and 61AB0 at 300 hours.

The results reported on Table XIX indicate that removing surge-stressed items does not improve the homogeneity of the 46 aircraft with 200 flying hours or the 14 aircraft with 300 flying hours.

D. CONCLUSIONS

The interval test indicates that surge-stressed items do fail differently than items not so stressed. The discrete test indicates that the airplanes are different in rate of failure and this difference is independent of the surge-stressed items.

The lack of confirmation of the two tests would tend to place the conclusion that surge affects the rate of failure and therefore the time to failure in doubt. The selection of aircraft to be flown in surge and the fact that these aircraft flew more hours on the average and therefore supplied more data to the study affects the conclusions. It cannot be assured that this bias is not the cause of the rejection of the Poisson in the interval test.

TABLE XIX
CHI SQUARE TEST OF VARIANCE-TO-MEAN RATIO
FOR NON-SURGE CONDITIONS

200 Hours

WUC	Mean	$s^2/\bar{x}$	$45(s^2/\bar{x})$	Poisson?
61AA0	0.65217391	1.17333	52.79985	
61AB0	0.47826087	1.18384	53.27280	
65BA0	0.47826087	0.90505	40.72725	
73NA0	1.56521739	1.49506	67.27770	reject at .975
73PA0	1.58695652	1.02435	46.09575	
73PB0	1.8695522	1.39328	62.69760	reject at .95
73PD0	2.23913093	1.49234	67.16025	reject at .90
73RB0	1.63043478	1.75437	78.94665	reject at .995
73RE0	3.10869565	1.04693	47.11185	

300 Hours

WUC	Mean	$s^2/\bar{x}$	$13(s^2/\bar{x})$	Poisson?
51ABH	0.50000000	1.15385	15.00005	
51CAC	0.42857143	0.97436	12.66669	
61AA0	0.71428571	0.52308	6.80004	
61AB0	0.50000000	1.15385	15.00005	
61AC0	0.42857143	1.33333	17.33329	
65BA0	0.78571429	1.60140	20.8182	
73NA0	1.92857143	2.19088	28.48144	reject at .99
73PA0	1.57143857	1.24476	16.18188	

TABLE XIX (Continued)

WUC	Mean	300 Hours $s^2/\bar{x}$	$45(s^2/\bar{x})$	Poisson?
73PB0	1.07142857	0.64103	8.33339	
73PD0	2.07142857	1.66844	21.68972	reject at .90
73RB0	1.50000000	1.20513	15.66669	
73RE0	3.00000000	0.76923	9.99999	

V. LIMITATIONS OF THE STUDY

A. INTRODUCTION

Every study has limitations in the ability to generalize from its findings. The limitations are primarily a function of the assumptions of adequacy in three areas, sample selection, data collection and data analysis. The limitations of this study are here discussed.

B. LIMITATIONS OF SAMPLE SELECTION

The sample selected for this study was the 27th Tactical Fighter Wing stationed at Cannon Air Force Base. The 27th Tactical Fighter Wing has F-111 aircraft in its inventory.

1) Only one aircraft type was used, the F-111D. The conclusions are therefore limited to that aircraft type. In a stricter sense, the conclusions are limited to the F-111D aircraft of the 27th Tactical Fighter Wing. In particular, the F-111 was chosen as a sample because of its characteristic as a digital system. It is more readily apparent when a digital system fails and the failure is more easily isolated than in an analog system. Consequently, while the results may be generalizable to other F-111 wings and perhaps to other aircraft which are digital systems, it would be more difficult to justify generalization to analog systems such as the F-4. Attempts to replicate this study on the F-4 aircraft at Moody Air Force Base failed for lack of continuous data over a sufficiently long period with respect to the average time to failure of the WRSK items. Even the generalization of the study findings to other F-111 and other digital systems may be questioned, and the tests may be replicated to determine generality.

2) The assumption implicit in the choice of Cannon Air Force Base is that the 27th Tactical Fighter Wing is typical of all F-111 Wings. Yet, with respect to maintenance records, they are superior. If that superiority is

prevalent in other maintenance procedures as well, the findings may loose generality.

3) The assumption is made that WUC's for which there are sufficient data for analysis are typical of all WUC's. The flying time for the aircraft ranged from 0 to 403.2 hours. Only those WUC's with relatively short mean time to failure generated a large number of intervals for analysis. These are items upon which the tests of distribution are based. If these items are fundamentally different from other WUC's, the study does not generate validly generalizable conclusions. Since the findings here are consistant with other studies found in the literature, the likelihood that these WUC's are different in their pattern of failure is remote. Nonetheless, some items may not fit the patterns found here.

C. LIMITATIONS OF DATA COLLECTION

The data collected for the study were extrated from existing Air Force records at the Air Force Base itself. No new data were generated for this study.

1) The assumption has been made that failure reports not verified are not failures. If there is no verification in the Action Taken Code, then the malfunction indication was dropped from the data and the interval continued. The effect of this assumption is to increase the individual times to failure since the recorded interval would have been divided into two or more by inclusion of unverified malfunctions. The effect of inclusion would be to shorten the mean time to failure, and make it easier to reject the Poisson process as descriptive of the data. The conservative method is to ignor unverified failures.

2) Because data were available for the two year period just prior to collection, it must be presumed that these are typical of all periods, and that the activities and mission profiles of these aircraft are typical of

general useage throughout the Air Force.

3) It must be assumed that the data collection during exercise Coronet Hammer was identical to data collection during normal conditions at Cannon Air Force Base.

D. LIMITATIONS OF ANALYSIS

The analysis of the data necessitates several assumptions which bear on the generalizability of the conclusions.

1) The assumption is made that the F-111D is a mature aircraft with a constant failure rate. New aircraft types introduced into Air Force inventory may exhibit a falling rate of failure due to improvement in manufacture or design based on feedback on performance of initial units deployed. Maintenance procedures and mechanics' learning also would lead to improvement in failure rate after introduction, though at some point, it is anticipated that failure rate would become constant or nearly so. The aircraft under study were introduced into Air Force inventory in 1968, twelve years before the data were collected. The assumption therefore, would appear justified.

2) The assumption is made that the previous history of the replacement item is irrelevant and does not effect future failures. The source of the replacement part may be from the WRSK, from depot or base repair functions, or the item may be new or cannibalized from other aircraft or from "hangar queens." The issue of new verses repaired items is not handled here. Whether the source of the replacement item effects the length of time that the replaced item functions cannot be analyzed with techniques used here. The data to determine the source of the replacement item was not recorded. If WRSK items are always new or reconditioned under special circumstances, the results of the study may not be generalizable from the failure distributions of items from more normal sources. Since this is not the case, and the WRSK

items will be drawn from the same selection of sources as captured here, the point is moot for this study, though that may not always be the case.

3) Insufficient data was collected to determine the effects on failure rate of mission profile. In order to determine these effects, mission profiles must be stipulated so that these sorties may be separated and tested against the base-line data gathered under normal useage.

4) The assumption is made that Coronet Hammer is a good representation of the conditions for which the WRSK would be employed. No information on the mission profiles is available. The data gathering, ability to determine valid failures, and the reporting of these failures is assumed to be the same as normal conditions at Cannon.

VI. CONCLUSIONS AND RECOMMENDATIONS

A. FAILURE DISTRIBUTIONS OF WRSK COMPONENTS

The Poisson process has been used for years in predicting reliability and maintenance behavior for many complex physical and electronic systems. The Poisson process, with exponential time-to-failure, is convenient and elegant. It is, however, apparently not accurate in describing the failure behavior of some components of the F111D airplane. This discrepancy is statistically significant in some cases.

It has been demonstrated here that the Poisson process does not describe some components of the F111D WRSK. It has also been demonstrated that failure behavior was not constant for different flying intervals. The demonstrated effects of surge on the WRSK components is to shift the distribution of times to failure of the fleet from the exponential, and the data is better described as negative binomial. Both the statistical analysis and the graphic demonstrations indicate that the Poisson process is not a bad approximation to the data and may be used for calculation of the logistic needs of the fleet. The general effect of approximating a negative binomial with a Poisson distribution is to initially underestimate the spares requirements and later overestimate them dependent upon the point at which the curves cross.

For the determination of WRSK configuration, however, using fleet data Poisson distributed will lead to error. It may well be that the distribution of failures under surge conditions is also Poisson, merely with a different mean, sufficiently different to distort the fleet data significantly away from the Poisson in some cases. Insufficient data was collected during Coronet Hammer to make a determination of its shape or parameters independent of other, non-surge data. Further investigation in this area is recommended. Determining the influence of surge was one of the objectives of this study,

but this objective has not been accomplished here due to ambiguous and contradictory results. The shifts of distributions from Poisson to negative binomial may be due to the particular airplanes from which data was collected, rather than from surge conditions.

Further empirical study of failure behavior is recommended because of the immense strategic and financial stake in the WRSK. A more extended study would pick up longer times between failures, and rarer single failures, than were obtained in this study. In order to conduct a more extended study, data covering several calendar years must be available. It is most strongly recommended that maintenance and flying records be maintained indefinitely in the field, for use in future empirical studies.

B. OTHER AREAS OF INVESTIGATION

The flying and maintenance data merging procedure used in this study has enormous potential as a tool to answer other questions than were addressed here. For instance, Is there a pattern of maintenance and failure behavior which precedes a crash, and which can be used to predict which airplanes are vulnerable to a crash? The historical records of planes which crashed due to equipment malfunction could be examined and compared with the records of other planes with similar operational background.

Similarly, the maintenance and failure behavior of planes operated in different climatic regions could be compared to determine what changes in maintenance behavior can be expected when planes are deployed from, for example, a desert to a subarctic region. It is possible that the changes would not simply involve the rate of failure of certain parts, but the pattern of failure as well, e.g., from a Poisson to a negative binomial failure process. An empirical study of this sort could be used in tailoring WRSK kits for specific contingency missions.

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APPENDIX I

SELECTED PROBABILITY DENSITY FUNCTIONS

Exponential: $f(t|\nu) = \nu e^{-\nu t}$, $0<t<\infty$

Poisson: $f(x;\mu) = \frac{e^{-\mu}\mu^{x}}{x!}$; $x=0,1,2...$

where μ is the average count.

In the compound Poisson process μ equals νl.

Gamma: $f(\nu;\ \kappa,\ \gamma) = \nu^{\kappa-1}e^{-\nu/\gamma}/\gamma^{\kappa}\Gamma(\kappa)$

where $\Gamma(\kappa) = \int_0^{\infty} x^{\kappa-1}e^{-x}dx$

Negative Binomial (Compound Poisson):

$$f(x;\kappa,\ell\gamma) = \binom{x+\kappa-1}{x}\frac{(\ell\gamma)^{x}}{(\ell\gamma+1)^{\kappa+x}}\ ;\ x=0,1...$$

Source: Bain and Wright, 1981

APPENDIX II

PROJECT - Air Force WRSK data analysis

USERS - Dr. Henry Metzner, Engineering Management

OBJECTIVE - scan a series of records depicting maintenance action, transforming this sequence of events into a set of intervals representing failure interarrival times. Correlate failure interval boundary dates with flying log records for each interval yielding a log record of flying information for each failure interval.
Statistical analysis may then be applied to the interarrival times to advise Air Force on efficient configurations of War Readiness Spares Kit, based on failure distributions.

SYSTEM COMPONENTS - IBM Job Control Language streams, PL/I programs, SAS and SAS/GRAPH programs, TSO CLISTs and CMS EXECs.

HARDWARE USED - Amdahl 470/V7 (node = UMMVSA), IBM 4341 (node = UMRVMB), IBM 3279 Color graphics terminal attached to UMMVSA, Tek (Tektronix) 4014 graphics terminal and 4662 plotter attached UMRVMB.

ORGANIZATION - The system components are designed to satisfy specific subsets of the overall objective. The majority is performed in the single application, MAINTLOG. Other components are used to provide support functions such as sorting and moving of datasets, and statistical and graphic functions. The breakout is into the following steps -

1. COMBINE - a JCL stream to

   a. merge several tapes of maintenance data (each containing only a few feet of data on a 2400' tape) into one large tape dataset.

   b. merge several flying tapes into a single tape containing two datasets, afbase.HISTORY and afbase.CURRENT, containing history data from archives and current data from online data, respectively.

2. MAINSRT - a PL/I program which invokes the SORT utility to create a sorted copy of the maintenance data, omitting data not used by the maintenance data logging routine.

3. FORMLOAD - a JCL stream to reformat the HISTORY and CURRENT flying information into a common format, then load the data into a VSAM ESDS with an alternate index.

4. MAINTLOG - a PL/I program with invoking JCL stream to log maintenance intervals and times to first failure, with flying information for each time period logged.

5. FLYREPT - a PL/I program and associated jobstream to produce cumulative flying hours per plane, to be used in selecting planes for computing count statistics.

6. GRAFEXP - a SAS/GRAPH program and associated CMS EXEC or TSO CLIST to product graphs, by WUC, of % survival rate vs. length of interval from interval log output by (4).

7. GRAFIND - a SAS/GRAPH program with EXEC or CLIST to produce graphs of mean time between failures per plane, by WUC, from failure intervals.

8. MEANS1 - a SAS program with JCL stream to produce means and variances for count data derived from two files produced by (4) (intervals and singles) and the flying summary produced by (5).

9. MEANS2 - a SAS programs with JCL stream to produce means and variances for interval data.

Detailed Component Descriptions

1. COMBINE - this JCL stream consists of 3 IEBGENER STEPS. The first utilizes a concatenation in the SYSUT1 file, with one DD statement per maintenance tape. The SYSUT2 file is for the new maintenance file, written at the highest density available (6250 BPI at this installation). Control statements placed in the input stream file SYSIN are used to reformat the records, omitting some unnecessary fields.

   The second step creates the HISTORY dataset from flying information derived from archived data. Each history tape is identified by one DD card in the concatenation for SYSUT1. SYSUT2 specifies the output file, which is named afbase.HISTORY, where "afbase" is the name of the base where the tapes originated.

   The third step is similar to the first except there is only one current tape in the input file SYSUT1 and the output file is called afbase.CURRENT.

2. MAINTSRT - this PL/I program calls the system SORT interface, PLISRTD, with input and output exit routines MNTINP and MNTOUT, respectively. MNTINP is used as the input routine (called the E15 exit in VS/SORT terminology) to provide input data for SORT, one record per invocation. This routine inserts the appropriate year ahead of the job control day and translates zeros to blanks in the WUC so they will collate correctly. MNTOUT, the SORT E35 exit, puts back the zeros and outputs the record.

3. FORMLOAD - this JCL stream consists of two IEBGENER steps and one IDCAMS step. The first IEBGENER step translates the HISTORY dataset in file SYSUT1 into the common format used in the final flying file and puts in into the dataset afbase.BOTH in the file SYSUT2. The control cards are stored in a member named HISTORY in a partitioned dataset and referenced

in file SYSIN.

The second IEBGENER step formats and appends the CURRENT dataset, using control cards in member CURRENT.

The third step invokes IDCAMS, the Access Method Services utility program, to define and build the VSAM Entry Sequenced Data Set (ESDS) and the alternate index, which allows keyed access to data with not necessarily unique keys. The control cards to perform these functions are in members afbasDEL and afbasAMS, where "afbas" is the name of the Air Force base, truncated to five characters if necessary.

4. MAINTLOG - this PL/I program is the central program in the system. The preceeding steps were performed, using simple system utilities, to massage the data into a simple format to be processed by this program. The output of this program supplies the primary inputs to the statistical analysis phase.

The program operates in a hierarchical fashion on groups of data. The largest group considered at one time is data for one aircraft.

For each aircraft, the data is further broken down into Job Control groups, that is, groups of maintenance actions having the same Job Control Number (JCN) and date.

Within a JCN group, the data is sorted by WUC. The program scans the group, building a list of maintenance actions taken for each WUC. Then those lists are checked to confirm removal (without which the actions are ignored) and to determine if a part failure is indicated. If a failure is indicated, then an entry with the job control date and WUC is made in the failure structure for the aircraft. If two failures have occurred previously, the interval between them is logged.

Following processing of the last JCN group for an aircraft, the failure structure is scanned, and the last interval for each WUC is

logged.

Logging of intervals is performed by the subroutine Log-Action, which invokes the subroutine FLYING to sum flying information from the VSAM ESDS over the period between two dates. If one or both dates lies outside the period specified in the JCL as the limits for this run, the interval is not logged.

5. FLYREPT - this program reads the flying ESDS sequentially and accumulates flying hours, landings, sorties and full stops for each aircraft.
6. GRAFEXP - this SAS/GRAPH procedure inputs maintenance intervals produced by (4), sorts the data by length of interval, obtains the means, calculates points along the exponential curve for Poisson-distributed data with the same mean, calculates percent surviving each unique interval length, and plots the curves along with the percent surviving by WUC.
7. GRAFIND - A SAS/GRAPH procedure which reads in interval values, calculates the mean time between failures for each aircraft/WUC combination, and graphs these means, by WUC.
8. MEANS1 - A SAS procedure to analyze count data. This procedure uses time to first failure and time between failures to provide a cutoff at x number of hours, so that only the failures occurring in that time are accepted. The flying time time summary produced in (5) is used to eliminate aircraft that flew less than x hours, and to include zero occurrence statistics in the means. The mean and variance are calculated, also the ratio between tham.
9. MEANS2 - A SAS procedure to print means, variances, and var/mean for interval data. Note that the x hours restriction no longer exists.

APPENDIX III

USE OF EXTRACTION PROGRAMS

NRFRMC

This program extracts data from the current MMICS (flight) data base. It may be run with the MMICS on line.

FORMAT

The format for NRFRMC is:

?EX NRFRMC
?DATA AFBRMR
(parameter card, as below)
?END

The "?" symbol represents the numerals 1, 2, and 3 overstruck in the same column. (Multipunch)

PREPARE CONTROL (PARAMETER) CARD

Before running this program, check with the MMICS operator to determine when a "Delete History" was last run (the system monitor may do this). For example, if a "Delete History" was run on 1 May 80, and the program is to be run on 18 September 80, then the control (parameter) card for program NRFRMC will appear as follows: columns 1 through 10 will be the inclusive Julian dates for the current data files, in this case "8Ø1228Ø262", columns 13 through 17 will be the type of aircraft, for example, "F111D", and column 19 will be the MMICS UNIT ID, for example, "A".

RUN NRFRMC

To run NRFRMC, the following MMICS file must be present on disk: ZRFØØA, ZRFØØB, ZRFØØC, and ZRFØØT. Load NRFRMC to disk. Read the appropriate execute deck, as described above, into the card reader. The program will produce an AFBRM1 list and an AFPRMP tape. These will contain the extracted data from the current data base.

TAPE OUTPUT

The FILE-ID of the output tape is AFBRMP. It is formatted in 80 character records. The blocking factor is 10 records.

PRINTED OUTPUT

The FILE-ID of the output is AFBRM1. This listing is an 80-80 list of the output tape and is in the same format as the tape record.

TABLE 1
FORMAT OF CONTROL (PARAMETER) CARD
NRFRMC (CURRENT FLIGHT EXTRACTION)

Card Column	Example	Remarks
1 - 5	80122	A five-digit numeric symbol giving the Julian date of the inclusive beginning day of the period from which data is to be extracted
6 - 10	80262	A five-digit numeric symbol giving the Julian date of the inclusive ending day of the desired period
11 - 18	--F111D-	The dashes represent blank spaces. This is nominally an eight character alpha-numeric symbol designating the type of aircraft for which data will be extracted, including three spaces for the mission, three for the design, and two for the series. If the standard designation of the aircraft, or MDS, does not use all eight spaces, as in the example, the symbol must be positioned so that each element lies in the appropriate field. If the program runs, but extracts no data, check the parameter card for an error in positioning here.
19	A	A single letter, the MMICS UNIT ID. This field may be left blank. If the field is left blank, all aircraft, regardless of unit of assignment, will be scanned.

TABLE 2
FORMAT OF TAPE OUTPUT
AFBRMP (CURRENT FLIGHT)
AND LIST OUTPUT AFBRM1

Byte Position	Example	Remarks
1 - 7	--F111D	The dashes represent blank spaces. A seven charcter alpha-numeric symbol, giving the MDS of the equipment (three places for the mission, three for the design, one for the series)
8 - 15	78ØØ5111	Eight-digit numeric symbol, giving the aircraft serial number
16 - 20	79152	Five-digit numeric symbol; a Julian date
21 - 23	Ø35	Three-digit numeric symbol; total hours and tenths flown on this date
24 - 27	LXSW	Four letters: the station location code
28 - 30	ØØ3	Three digit number; the total number of landings on this date
31 - 33	ØØ2	Three digit number; total number of sorties flown on this date
34 - 42	ØØ32TFWCE	Nine characters; number, kind and type of owning unit
43 - 45	ØØ2	Three-digit number; total full stop landings this date
46 - 70		25 blank filler
71 - 75	A5111	Five character alpha-numeric; MMICS equipment-ID
76 - 80	ØØØØ1	Five-digit number; record sequence number

NFBRAA

This program runs against the MMICS (flight) history tapes (ARF53T).

FORMAT

The format for NFBRAA is:

?EX NFBRAA DATA AFBROC
(parameter card, as below)
?END

The "?" symbol represents the numerals 1, 2, and 3 overstruck in the same column. (Multipunch)

CONTROL (PARAMETER) CARD

This program must be run against every ARF53T tape that is in the library, going as far back as the data extraction is desired. There may be one ARF53T tape for each month, or the base may create an ARF53T with several months of data. Contact the MMICS operator to find out how much data is on each tape (the system monitor may do this). For example, if program NFBRAA is being run against an ARF53T tape that contains data for August 1980, then the Julian dates on the control card will be 8Ø214 to 8Ø244. The format on this card is the same as the format for the control card for program NRFRMC.

OUTPUT

The output of NFBRAA includes a list coded AFBRMR. Note that it is not formatted the same as the output of NRFRMC.

TABLE 3
FORMAT OF NFBRAA OUTPUT (FLIGHT HISTORY)
AFBRMR

Column	Example	Remarks
1 - 8	68ØØØ511	Equipmepnt ID; in this case the airplane's tail number. Eight digits
9 - 15	--FØØ4E	The dashes represent blank spaces. Seven characters giving the Mission Design Series, with three places for the Mission, three for the Design, and one for the Series
16-20	8Ø111	Five digits giving the Julian date
21 - 23	Ø25	Three digits; total hours and tenths flown on this date
24 - 27		Blank
28 - 29	Ø1	Two digit number; total landings this date
30 - 31	Ø1	Two digit number; total number of sorties flown on this date
32 - 40	Ø347TFGWG	Nine characters; number, kind and type of owning unit
41 - 43	ØØ1	Three digits; total full stop landings this date
44 - 80		Blank

NBDQ99

This is the object code for the program to extract MDC (maintenance) data. This program is run against the 6-month history ABD6DA tapes for MDC. Each run will take approximately two to three hours of processing time.

FORMAT

The format for NBDQ99 is as follows.

?EX NBDQ99
?DATA ABFQ9C
(card deck, as below)
?END

The "?" symbol stands for the numerals 1, 2, and 3 overstruck in the same column. (Multipunch)

CARD DECK

The card deck will consist of one "A" card, several "B" cards, and one or more "C" cards. Depending on how many WUC's have been selected for data extraction, more than one card deck may be required. No more than 150 WUC's may be included in a deck.

The "A" card specifies the type of aircraft and the time span (within the period covered by the history tapes) to be scanned.

The "B" cards, up to ten of them, list those WUC's regarding which maintenance data is to be extracted.

The "C" cards specify which individual airplanes are to be included. Up to 105 may be listed, or one card may be used if all airplanes are to be included.

OUTPUT

Output will be an ABFQ9P tape and an ABFQ9L list.

SPECIAL NOTE

It is not possible to extract data regarding a sub-component (an item with the lowest level WUC, such as 73CAH) unless its parent component (such as 73CAØ) is included in the extraction list. It is not necessary to include all other subcomponents in order to gather data on that single desired subcomponent. If more than one deck of WUC's is necessary, the parent component and the subcomponent must be run together. This may mean repeating the parent component in two runs if a subcomponent list must be broken up.

TABLE 4
FORMAT OF INPUT TO NBDQ99 (MAINTENANCE EXTRACTION)
"A" CARD

Column	Example	Remarks
1	A	"A"
2 - 10		Blank
11 -17	--FØØ4E	The dashes represent blank spaces. A seven-character alpha-numeric symbol giving the MDS of the airplane; three places for the mission, three for the design, three for the series. If the standard designation of the aircraft does not use all seven spaces, as in the example, the symbol must be positioned so that each element lies in the appropriate field. If the program runs, but extracts no data, check the "A" card for an error in positioning here.
18 - 29		Blank
30 - 39	793Ø779365	The inclusive Julian dates covering the period regarding which data is to be extracted
	-or-	
30 - 32	ALL	If the entire period covered by this ABD6DA tape is of interest.
40 - 80 -or- 33 - 80		Blank

TABLE 5
FORMAT OF INPUT TO NBDQ99 (MAINTENANCE EXTRACTION)
"B" CARDS

Column	Example	Remarks
1	B	"B"
2 - 5		Blank
6 - 80	23CAØ23CAA23CAB.....	Starting in column six, the card may be filled with five-character WUC's. Each card will hold fifteen WUC's, and up to ten such cards may be used in the deck each time NBDQ99 is run. Each card must begin with the "B" and four blank spaces

TABLE 6
FORMAT OF INPUT TO NBDQ99 (MAINTENANCE EXTRACTION)
"C" CARDS

Column	Example	Remarks
1	C	"C"
2 - 5		Blank
6 - 80	A4Ø95A4Ø96....	Starting in column six, the card is filled with five-character equipment ID's, of which the first character is the prefix of the equipment classification code, in the example "A" for aircraft, and the last four characters are the last four positions of the equipment serial number, in this case, the aircraft tail number. Each card will hold up to fifteen equipment ID's, and up to seven such cards may be used, for a possible total of 105 airplanes Each card must begin with the "C" and four blank spaces
	--or--	
6 - 8	ALL	If data regarding all airplanes on the tape are to be extracted
9 - 80		Blank

TABLE 7
FORMAT OF ABFQ9L (MAINTENANCE) LIST

Note--for a full explanation of all symbols, see AFLC/AFSC P 400-11 paragraph 9-4.

Column	Example	Remarks
1 - 7	--FØØ4E	The dashes represent blank spaces. A seven character alpha-numeric symbol, giving the MDS of the airplane; three places for the mission, three for the design, one for the series
8 - 15	69ØØ7303	Eight digits giving the airplane's serial number, or tail number
16	Ø	Units Completed. Units of work completed. See AFLC/AFSC P 400-11, 9-4c (7)
17 - 23	2993273	Job Control Number; the first three digits are the Julian day the Job was initiated; the last four digits are a unique identifier for work begun on that day. These digits may be coded to identify the purpose of the work, or may carry other information besides just the sequence of work on that date
24 - 27	QSEU	Station location code
28 - 32	522EØ	Work Unit Code. A five-character alpha-numeric symbol identifying a system, subsystem, component (as in the example) or subcomponent of the airplane on which this maintenance action was accomplished
33	F	Action taken code. A single character representing the maintenance action accomplished
34	P	When discovered. A single digit or numeral indicating when the malfunction was discovered
35 - 37	255	How malfunctioned; a three digit number representing the type of equipment failure motivating the maintenance action

Column	Example	Remarks
38 - 39	78	Year
40 - 42	319	Stop day; the Julian date this action (see the action taken code) was completed; this is not necessarily the final action that will be taken under this job control number
43 - 46	6615	Federal supply class; supply category of equipment. This may be left blank if no supply action is involved
47 - 55	753Ø88110	The dashes represent blank spaces. A nine-character part number. May be blank, if no supply action is involved
56 - 61		Blank
62 - 66	A73Ø3	ID Number. Consists of the last five characters of the six-character ID number described in AFLC/AFSC P 400-11, 9-4 (3): The first character is the prefix of the equipment classification code, in the example "A" for aircraft; The last four characters are normally the last four positions of the equipment serial number; thus, columns 64-66 should duplicate columns 12-15.
67 - 75	Ø34TFGWG	Organization; number, kind, and type
76 - 80	ØØ953	Sequence number; this is a record count for each entry

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
8Ø12280262  F111D A
```

Figure 1. Example of Control Card for NRFRMC

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
  F111D78ØØ511179152Ø35LXSWØØ3ØØ2ØØ32TFWCEØØ2                      A5111ØØØØ1
```

Figure 2. Example of NRFRMC Output

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
68ØØØ511  FØØ4E8Ø111Ø25    Ø1Ø1Ø347TFGWGØØ1
```

Figure 3. Example of NFBRAA Output

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
A           FØØ4E            793Ø779365
A           FØØ4E            ALL
```

Figure 4. Two Examples of NBDQ99 "A" Card

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

B    23CAØ23CAA23CAB23CAC23CAD61AEØ61AEA61AEF61AEG71H4Ø71H4F71H4R71H2Ø71H2S74CPØ
```

Figure 5. Example of NBDQ99 "B" Card

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

C    ALL
```

Figure 6. Example of NBDQ99 "C" Card

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

  FØØ4E69ØØ73Ø3Ø2993273QSEU522EØFF25578319661575 3Ø8811Ø      A73Ø3Ø347TFGWGØØ953
```

Figure 7. Example of ABFQ9L List

DAT

FILM

0 -